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PUBLICATIONS OF THE EARTHQUAKE INVESTIGATION
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Observation of Local Earthquakes on Mount Tsukuba, in 1905.

By

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With Pls. I—VI.

Place of observation. The present paper is a preliminary report on the seismometrical measurements made in 1905 at H.I.H. Prince Yamashina's meteorological station at Tsukuba, a small town at mid-height of the southern slope of the Tsukubasan. The latter is a mountain of granite and diorite formations, which is situated in the south-western part of the province of Hitachi, and which rises, almost as a solitary mass, to an elevation of 870 metres, directly out from the low plain bordering the lower course of the river Tone and the Kasumiga-ura. The geographical position of the meteorological station in question, which is 240 metres above the sea level, is $\varphi=36^{\circ} 12' 22''$ N., $\lambda=140^{\circ} 5' 56''$ E. A full account of these earthquake observations as well as those made at His Highness' Meteorological Observatory, established in 1901, at the top of one of the double peaks of the Tsukubasan, will be given as an appendix to the "Ergebnisse der meteorologischen Beobachtungen auf dem Tsukubasan."

Instrument. The observations, whose object was the study of the near earthquakes, were made with an EW component

The observations have been carried on by Mr. J. Sato, chief observer of the Tsukuba observatories, Mr. H. Tsutsui, assistant observer, and others.

List of the earthquakes observed in 1905. The tremor-recorder is sensible only to the quicker component of the seismic motion, and recorded, in 1905, four hundred and eighty-seven earthquakes, whose epicentral distances were each less than 1,000 km, which is nearly equal to the distance of the Tsukuba-san from either the north-eastern end of Hokkaido on the north, or the northern part of Kyushu on the south-west. The accompanying list gives for the EW component of each of these shocks the following particulars:—

- (1) Date.
- (2) Time of earthquake occurrence, given in the 1st Normal Japan Time, or that of longitude 135° E. of Greenwich.
- (3) Intensity of motion, distinguished as *slight*, or *moderate*. None of the earthquakes was *strong* or *destructive*.*
- (4) Total duration.
- (5) Duration of the preliminary tremor.
- (6) Maximum range of motion in the preliminary tremor.
- (7) „ „ „ „ principal portion.
- (8) Remarks.

The preliminary tremor was in most cases quite sharply defined.

* The intensity of the non-destructive earthquake motion is indicated as slight, moderate, or strong. A slight shock is one which is very feeble and just enough to be felt; a moderate shock is one whose motion is well-pronounced but not so severe as to cause general alarm; and a strong shock is one which is sufficiently intense to cause people to run out of doors, to overturn furnitures, etc.

List of 487 Earthquakes observed on Mount Tsukuba
in 1905.

(* denotes an *insensible* shock.)

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	January.						
1	h m s 4 30 30 a.m.	Slight.	sec. 106	sec. 16.4	mm. 0.010	mm. 0.082	
"	8 53 10 p.m.	Do.	26	14.2	—	0.013	
2	2 27 25 a.m.	*	37	11.3	—	0.006	
"	4 25 30 a.m.	*	31	8.2	0.007	0.014	
5	0 25 06 a.m.	Slight.	30	5.6	0.004	0.028	Accompanied by loud sound.
7	10 57 00 a.m.	Moderate.	64	9.9	0.013	0.033	
9	4 00 50 p.m.	*	29	9.4	—	0.009	Sound only perceived.
11	1 23 10 a.m.	*	23	8.7	—	0.011	Do.
13	11 25 30 a.m.	Slight.	23	6.0	0.006	0.044	Accompanied by sound.
14	1 09 00 p.m.	*	40	41.0	—	0.002	
"	5 38 30 p.m.	Moderate.	65	5.9	0.004	0.058	Accompanied by sound.
17	4 19 00 a.m.	Slight.	22	6.7	0.015	0.080	
"	10 59 20 a.m.	Do.	36	10.4	—	0.008	Accompanied by sound.
21	7 44 27 a.m.	Do.	35	5.9	—	0.011	Accompanied by loud sound.
"	5 29 00 p.m.	*	70	6.0	—	0.004	Sound only perceived.
22	2 53 00 a.m.	Slight.	78	13.1	0.008	0.026	
"	0 58 40 p.m.	*	16	8.1	—	0.039	
25	8 30 37 p.m.	Slight.	31	8.4	0.011	0.060	
26	1 55 15 p.m.	*	—	10.3	—	—	
"	4 02 30 p.m.	Moderate.	106	11.0	0.028	0.220	
"	5 19 28 p.m.	*	120	46.0	—	0.003	
"	7 14 10 p.m.	*	90	(?)	—	0.004	Origin distant.
27	9 23 10 p.m.	*	60	(?)	—	0.002	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion	
	January.						
28	h m s 1 48 30 a.m.	*	sec. 30	sec. 6.6	mm. —	mm. —	
	February.						
2	8 17 00 a.m.	*	133	63.0	—	0.010	
"	9 08 25 a.m.	Slight.	98	24.0	—	0.022	
4	0 54 30 a.m.	Do.	30	9.5	0.020	0.037	
	3 58 00 p.m.	*	35	11.6	—	0.022	
6	5 21 00 a.m.	*	40	16.8	—	0.017	
7	11 33 00 a.m.	*	85	22.5	—	0.011	
"	2 46 45 p.m.	Moderate.	100	17.0	0.036	0.120	
"	8 49 05 p.m.	Slight.	20	0.0	—	0.072	Accompanied by loud sound.
11	7 03 30 a.m.	Moderate.	70	25.0	0.022	0.073	Accompanied by sound.
13	1 55 10 p.m.	Slight.	32	8.0	—	0.010	Do.
14	10 55 45 p.m.	Moderate.	140	18.5	0.001	0.047	Do.
15	10 13 00 a.m.	*	65	16.4	—	0.022	
"	5 29 30 p.m.	Slight.	66	7.1	0.011	0.038	Accompanied by sound.
"	9 12 00 p.m.	*	20	0.0	—	0.022	
17	2 06 40 a.m.	Slight.	21	0.0	—	—	Accompanied by sound.
"	3 27 25 a.m.	Do.	87	19.5	0.009	0.054	Do.
"	10 56 30 a.m.	*	14	8.0	—	0.016	Do.
"	5 14 25 p.m.	Slight.	72	5.7	0.013	0.076	Do.
"	6 44 30 p.m.	Moderate.	144	14.1	0.027	0.180	Do.
18	6 56 05 p.m.	Slight.	100	10.1	—	0.024	Do.
"	7 08 10 p.m.	*	36	13.2	—	—	Sound only perceived.
20	1 47 33 p.m.	Slight.	24	8.5	0.012	0.064	Accompanied by sound.
21	2 26 30 p.m.	*	44	0.0	—	—	Sound only perceived.
23	9 03 20 a.m.	*	46	6.0	—	—	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
February.							
23	^{h m s} 11 35 00 p.m.	*	^{sec.} 24	^{sec.} 9.2	^{mm.} 0.004	^{mm.} 0.010	
24	4 18 50 a.m.	Slight.	40	14.1	0.004	0.038	
25	2 45 00 a.m.	*	34	7.7	—	0.010	
"	3 13 00 a.m.	*	—	—	—	—	Only loud sound perceived.
"	6 44 15 a.m.	Moderate.	47	14.3	0.017	0.098	Accompanied by sound.
"	0 54 00 p.m.	*	22	7.0	0.003	0.008	
27	1 19 45 a.m.	Slight.	59	12.1	0.009	0.036	Accompanied by sound.
March.							
3	4 12 05 p.m.	*	53	6.0	0.004	0.012	
"	5 17 40 p.m.	*	20	7.1	—	0.014	
4	3 39 45 a.m.	Slight.	43	8.9	—	0.024	Accompanied by sound.
"	9 18 30 p.m.	Moderate	76	9.0	0.022	0.170	Do.
6	6 04 25 a.m.	Slight.	40	8.2	0.004	0.047	Accompanied by sound.
"	6 08 15 a.m.	Do.	65	8.8	0.004	0.060	Do.
8	7 04 00 a.m.	*	47	15.3	—	0.012	
9	3 33 00 a.m.	Slight.	183	14.6	0.024	0.057	Accompanied by sound.
12	8 19 30 a.m.	Do.	34	11.3	0.002	0.014	Do.
"	8 12 30 p.m.	Do.	21	6.2	0.020	0.043	Do.
14	4 10 45 p.m.	*	49	8.4	0.004	0.028	
"	7 16 40 p.m.	*	33	11.0	—	0.006	
16	1 06 11 p.m.	Slight.	41	9.4	0.024	0.044	Accompanied by sound.
18	1 09 35 p.m.	Do.	33	11.8	0.006	0.060	Do.
"	10 30 00 p.m.	Do.	27	7.0	—	0.039	Do.
19	11 11 30 p.m.	*	64	35.0	—	0.009	
21	2 53 20 a.m.	Slight.	63	7.8	—	0.021	Accompanied by sound.
"	10 57 25 a.m.	Do.	106	36.0	0.002	0.020	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion	
	March.						
23	h m s 7 02 25 a.m.	*	sec. 67	sec. 15.0	mm. —	m.m. 0.013	
"	5 59 00 p.m.	Slight.	40	13.1	0.007	0.038	Accompanied by sound.
24	11 16 00 a.m.	*	31	14.2	—	0.009	
25	2 00 00 a.m.	*	52	19.5	—	0.006	
26	8 04 00 a.m.	Slight.	20	3.5	—	0.028	Accompanied by sound.
"	9 33 30 p.m.	*	18	5.2	0.002	0.039	
	April.						
3	7 50 00 p.m.	*	94	18.6	—	—	{ Loud sound heard toward S., 5 or 6 sec. before the shock. Houses were much shaken, and liquids thrown out. The rain gauge was displaced slightly toward SW.
6	9 29 10 p.m.	Moderate.	68	6.7	0.093	0.490	
"	11 33 40 p.m.	*	39	6.3	0.003	0.029	
10	0 25 30 a.m.	*	34	9.6	0.004	0.021	
11	3 44 40 a.m.	*	21	0.9	—	0.038	
12	7 23 10 a.m.	*	19	6.0	0.003	0.042	Sound only perceived.
13	0 37 25 p.m.	*	51	17.2	—	0.016	
"	6 02 40 p.m.	Slight.	70	9.0	0.018	0.064	{ Loud sound heard toward S. before the shock.
14	1 00 00 a.m.	*	21	7.3	—	0.011	
"	7 37 00 a.m.	Slight.	48	25.2	—	0.044	
17	3 11 05 a.m.	■	31	7.8	—	0.028	
"	7 13 00 p.m.	*	123	65.0	—	0.006	
9	1 02 00 a.m.	*	10	5.6	—	0.006	
"	5 29 00 a.m.	*	35	10.3	—	0.004	
20	8 45 20 a.m.	*	45	17.4	—	0.016	
21	1 28 00 a.m.	*	24	7.4	—	0.011	
"	11 07 30 p.m.	*	42	7.7	—	0.006	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	April.						
	h m s		sec.	sec.	mm.	mm.	
22	3 34 00 a.m.	*	84	17.3	—	0.008	
24	1 04 00 a.m.	*	85	22.2	—	0.016	
..	5 15 02 a.m.	Moderate.	65	15.7	0.017	0.153	Accompanied by sound.
..	6 31 00 a.m.	Do.	60	11.6	0.024	0.004	Do.
25	3 42 00 a.m.	*	45	8.5	—	0.016	
27	0 31 00 p.m.	Slight.	18	5.4	0.004	0.021	{ Loud sound heard toward SW.
29	7 17 30 a.m.	*	Very Short.	0.0	—	—	{ The diagram consisted only of a single stroke.
30	9 34 10 a.m.	*	50	12.2	0.013	0.024	
..	7 37 30 p.m.	Slight.	25	4.9	—	.036	{ Preceded by loud sound, which was heard toward S. The principal portion of the diagram lasted only 3.5 sec.
	May.						
2	3 00 45 p.m.	*	58	9.8	—	0.016	
4	5 51 50 p.m.	*	11	0.0	—	0.014	
5	4 04 05 a.m.	*	28	8.7	—	Small.	
..	8 13 20 a.m.	*	30	9.0	—	0.010	
7	6 27 00 p.m.	*	40	10.6	—	0.004	
..	10 20 10 p.m.	*	39	6.1	—	0.016	
..	10 24 20 p.m.	*	100	35.0	—	Small.	
8	8 12 55 p.m.	Moderate.	80	19.0	—	0.051	Accompanied by sound.
9	2 54 10 a.m.	Do.	143	11.0	0.051	0.204	Loud sound heard toward S.
13	7 32 00 p.m.	*	31	7.9	—	0.004	
15	8 07 25 a.m.	Slight.	53	9.2	0.017	0.061	Accompanied by sound.
16	2 51 00 a.m.	*	52	8.3	—	0.029	
17	2 06 30 a.m.	*	130	62.0	—	0.013	
..	8 32 10 a.m.	*	50	5.2	—	0.011	
..	10 03 00 a.m.	Slight.	43	5.3	0.006	0.044	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
May.							
	h m s		sec.	sec.	mm.	mm.	
20	4 53 30 p.m.	*	95	49.3	—	0.016	
22	6 23 30 p.m.	*	30	8.9	0.008	0.024	
23	5 18 15 a.m.	*	23	6.1	0.006	0.028	
"	1 33 25 p.m.	*	50	7.4	—	0.028	
"	7 45 00 p.m.	*	70	12.3	—	0.014	
24	8 32 30 p.m.	Slight.	109	41.0	—	0.024	
25	1 29 30 a.m.	Do.	41	5.2	0.009	0.077	
26	2 00 25 a.m.	Do.	60	10.1	0.010	0.058	Accompanied by sound.
"	3 46 50 p.m.	Moderate.	107	19.4	0.043	0.160	{ Loud sound heard toward S., 3 sec. before the shock.
28	0 50 00 a.m.	*	17	—	—	Small.	
"	1 49 00 a.m.	*	18	—	—	"	
31	8 56 00 p.m.	*	65	12.0	0.002	0.011	
June.							
2	1 17 50 p.m.	*	27	8.3	—	0.017	
3	0 44 30 a.m.	*	53	15.0	—	0.006	
"	11 21 30 a.m.	Slight.	53	8.8	0.004	0.016	Accompanied by sound.
4	8 45 30 a.m.	*	70	6.4	—	0.003	
5	8 43 30 a.m.	*	35	(P)	—	0.008	
"	10 01 30 a.m.	*	25	8.9	—	0.008	
6	0 40 00 a.m.	*	28	(P)	—	Small.	
"	0 43 00 a.m.	*	31	19.6	—	0.007	
"	1 13 00 a.m.	*	55	19.1	—	0.009	
"	1 18 00 a.m.	*	40	(P)	—	0.004	
6	1 49 00 a.m.	*	57	18.0	—	0.013	
"	2 04 00 a.m.	*	62	21.2	—	0.019	
"	2 25 00 a.m.	*	60	17.8	—	0.008	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	June.						
	h m s		sec.	sec.	mm.	mm.	
6	2 27 00 a.m.	*	60		—	Small.	
..	5 17 00 a.m.	*	58	20.3	—	0.009	
..	5 57 30 a.m.	Moderate.	54	7.0	0.013	0.106	{ Loud sound heard toward SW.
..	9 19 00 a.m.	*	8	?	—	Small.	
..	9 23 00 a.m.	*	27	?	—	0.009	
..	11 45 30 a.m.	*	10	?	—	Small.	
7	6 12 30 a.m.	Moderate.	74	6.1	0.032	0.190	{ Loud sound heard toward SW.
..	2 39 50 p.m.	Do.	75	17.7	0.027	0.093	{ Loud sound heard toward SE.
..	2 41 05 p.m.	Slight.	91	17.2	0.027	0.093	
..	3 28 50 p.m.	*	10	?	—	Small.	
..	3 41 50 p.m.	*	7	?	—	..	
..	3 42 30 p.m.	*	—	18.3	—	0.008	
..	10 05 30 p.m.	*	40	16.7	—	0.031	
10	3 09 50 p.m.	Slight.	106	36.4	0.017	0.042	Accompanied by sound.
11	11 50 10 p.m.	Moderate.	49	5.6	0.066	0.220	{ Loud sound heard toward SW., 3 sec. before the shock.
12	5 17 30 p.m.	Do.	154	18.4	0.054	0.190	{ Sound heard toward S., 5 sec. before the shock, and ceased during the motion.
13	2 48 30 p.m.	*	95	29.0	—	Small.	
14	8 44 30 a.m.	*	28	11.1	—	0.012	
16	7 08 20 p.m.	*	20	?	—	Small.	Origin-distant.
17	2 12 00 a.m.	*	20	7.7	—	0.007	
..	5 33 00 a.m.	*	30	?	—	Small.	Origin distant.
18	1 16 24 a.m.	Moderate.	100	13.2	0.023	0.190	Accompanied by sound.
..	2 15 30 a.m.	*	15	?	—	Small.	Origin distant.
..	3 33 15 a.m.	*	25	?	—	0.013	Do.
..	9 50 00 a.m.	*	10?	?	—	0.016	Do.
..	11 02 00 a.m.	*	5	?	—	0.021	{ The diagram consisted of a single stroke.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion	
June.							
19	^{h m s} 6 38 30 a.m.	Slight.	^{sec.} 18	^{sec.} 6.6	^{mm.} —	^{mm.} 0.027	Accompanied by sound.
20	5 31 00 a.m.	Do.	75	13.3	0.007	0.050	Do.
"	0 34 10 p.m.	*	15	6.1	—	0.010	
"	0 37 40 p.m.	*	145	114.0	—	0.009	
26	1 23 00 a.m.	Slight.	55	16.0	0.012	0.056	Accompanied by sound.
"	1 38 20 p.m.	Do.	50	13.3	0.008	0.039	{ Loud sound heard toward S.
27	1 09 30 a.m.	*	160	54.0	0.007	0.039	
"	3 17 10 a.m.	Slight.	50	12.1	0.023	0.183	Accompanied by sound.
"	3 46 30 p.m.	*	35	9.9	—	0.006	
29	10 29 00 a.m.	Slight.	30	8.1	0.002	0.008	Accompanied by sound.
"	4 59 00 p.m.	*	20	7.1	0.002	0.007	
July.							
2	10 58 00 p.m.	*	10	?	—	0.002	
3	4 43 00 p.m.	*	30	17.8	—	0.008	
"	11 14 20 p.m.	*	40	10.3	—	0.002	
4	6 53 20 p.m.	*	?	13.1	—	0.013	
5	2 03 30 a.m.	*	30	13.2	0.003	0.007	
"	9 00 30 a.m.	*	60	?	0.006	0.011	Origin distant.
"	2 37 10 p.m.	Slight.	40	10.1	0.003	0.010	Sound heard toward S.
7	1 21 25 a.m.	Moderate.	275	?	0.032	0.690	Origin distant. No sound.
"	1 26 00 a.m.	Slight.	95	32.0	0.012	0.071	
"	4 51 40 a.m.	*	35	?	—	0.010	Origin distant.
"	7 17 25 a.m.	Moderate.	225	62.0	0.077	0.170	Accompanied by sound.
"	9 06 30 a.m.	*	25	?	—	Small.	Origin distant.
"	10 19 00 a.m.	*	20	?	—	0.006	Do.
"	10 33 00 a.m.	*	100	60.0	0.006	0.011	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	July.						
	h m s		mm.	sec.	mm.	mm.	
7	9 27 45 p.m.	*	50	9.9	—	0.016	
„	10 38 35 p.m.	*	70	?	—	0.013	Origin distant.
8	3 13 00 a.m.	*	70	37.5	—	0.014	
„	7 20 30 a.m.	*	20	?	—	Small.	Origin distant.
„	11 08 00 a.m.	*	50	23.0	—	0.018	
9	7 11 55 a.m.	Moderate.	160	29.3	0.050	0.150	Accompanied by weak sound.
„	7 21 30 a.m.	*	15	?	—	0.004	Origin distant.
„	11 23 00 a.m.	Slight.	45	9.1	—	0.049	Accompanied by loud sound.
10	2 49 20 a.m.	*	60	?	—	0.003	Origin distant.
„	7 55 00 a.m.	*	—	28.0	—	0.010	
11	4 55 00 a.m.	*	30	10.1	—	0.023	
„	6 18 25 a.m.	Slight.	105	22.5	0.012	0.048	Accompanied by sound.
12	0 38 25 a.m.	*	75	?	—	0.024	Origin distant.
„	0 41 00 a.m.	*	90	?	—	0.067	Do.
„	11 56 10 a.m.	*	21	4.7	0.002	0.004	Loud sound heard toward S.
13	5 05 15 a.m.	*	50	?	—	Small.	Origin distant.
„	1 53 00 p.m.	*	50	?	—	Do.	Do.
„	9 27 25 p.m.	*	40	?	—	0.004	Do.
14	6 02 30 a.m.	*	40	?	—	Small.	Do.
„	3 56 45 p.m.	*	75	18.2	—	0.011	
„	11 17 20 p.m.	*	—	9.5	—	0.003	
15	3 09 10 a.m.	Slight.	20	5.3	0.003	0.027	Accompanied by sound.
„	8 01 55 a.m.	Do.	60	11.5	0.004	0.033	Do.
„	7 07 30 p.m.	*	50	9.7	—	0.036	
16	3 38 25 p.m.	*	20	9.7	—	0.007	
„	4 03 30 p.m.	*	45	7.0	—	0.014	
19	3 27 30 a.m.	*	35	?	—	0.006	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion	
	July.						
	h m s		sec.	sec.	mm.	mm.	
19	5 03 12 p.m.	Moderate.	70	9.3	0.022	0.120	
"	6 39 00 p.m.	*	40	?	—	Small.	Origin distant.
20	4 33 15 a.m.	Slight.	25	5.7	—	0.022	Accompanied by sound.
"	5 35 20 a.m.	Do.	15	8.0	0.002	0.061	Do.
"	11 54 00 a.m.	Do.	30	4.4	0.027	0.082	{ Sound heard toward SW. before the shock.
"	5 49 10 p.m.	Slight.	55	?	—	0.028	
21	6 03 00 a.m.	*	75	10.9	—	0.039	
22	6 15 10 p.m.	*	70	28.0	—	0.007	
"	11 58 30 p.m.	*	26	?	—	Small.	Origin distant.
23	5 25 30 p.m.	Slight.	86	25.0	—	0.056	Accompanied by sound.
"	6 27 00 p.m.	Do.	40	19.7	—	0.051	Do.
"	7 00 20 p.m.	Moderate.	105	19.0	0.031	0.107	Sound heard toward S.
24	6 11 05 a.m.	*	60	?	—	Small.	Origin distant.
25	3 09 30 a.m.	*	45	?	—	0.017	Do.
26	0 49 20 a.m.	*	60	20.0	—	0.003	
"	1 04 30 a.m.	*	60	11.4	—	0.007	
"	4 30 07 a.m.	Slight.	55	6.2	0.016	0.073	{ Loud sound heard toward SW.
"	2 40 35 p.m.	Do.	65	16.0	—	0.022	
"	4 16 30 p.m.	*	60	20.5	—	0.028	
27	1 38 15 a.m.	Moderate.	100	7.9	0.039	0.340	Accompanied by loud sound.
"	2 09 30 p.m.	*	35	?	—	0.006	Origin distant.
29	4 57 30 a.m.	*	60	?	—	0.016	Do.
"	6 05 45 a.m.	Slight.	30	6.9	—	0.060	{ Loud sound heard toward SW., before the shock.
30	3 36 00 a.m.	*	90	58.0	—	0.007	
"	1 27 15 p.m.	*	?	32.5	—	Small.	
"	10 46 00 p.m.	*	30	?	—	Do.	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	August.						
	h m s		sec.	sec.	mm.	mm.	
1	8 08 30 a.m.	*	20	8.8	—	0.006	
2	4 24 20 a.m.	*	40	?	—	Small.	Origin distant.
..	2 17 50 p.m.	*	40	?	—	Do.	Do.
4	3 40 00 a.m.	*	95	30.0	0.008	0.018	
..	8 51 30 a.m.	*	85	30.0	0.003	0.024	
..	9 02 00 a.m.	*	60	30.0	—	Small.	
5	2 29 30 p.m.	*	45	—	—	Do.	Origin distant.
6	9 19 00 a.m.	*	40	?	—	0.003	
..	6 28 40 p.m.	*	50	12.2	—	0.006	
9	5 17 20 a.m.	Slight.	45	16.2	0.003	0.076	Accompanied by sound.
10	6 26 10 p.m.	*	55	15.7	—	0.012	
..	9 00 45 p.m.	*	50	?	—	Small.	Origin distant.
11	0 19 25 a.m.	*	110	23.6	0.011	0.028	
12	9 27 30 p.m.	Slight.	40	8.3	—	0.039	Accompanied by sound.
15	9 23 30 a.m.	*	60	?	—	Small.	Origin distant.
..	10 40 30 a.m.	*	140	69.0	—	0.011	
..	5 12 50 p.m.	*	100	?	—	0.009	Origin distant.
..	5 37 10 p.m.	*	100	?	—	Small.	Do.
16	7 47 21 a.m.	*	50	19.4	—	0.003	
..	9 02 51 a.m.	*	80	27.0	—	0.011	
17	9 37 10 p.m.	*	80	30.0	—	0.030	
18	1 08 43 a.m.	Slight.	90	9.0	0.008	0.053	Accompanied by sound.
..	10 51 38 a.m.	*	60	19.0	—	0.006	
20	0 47 40 a.m.	Slight.	10	2.5	—	0.022	{ Accompanied by loud sound. The diagram consisted almost only of a single stroke.
21	2 28 37 a.m.	*	40	?	—	0.002	
22	11 32 07 p.m.	*	90	35.0	—	0.006	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
August.							
23	^{h m s} 2 03 42 p.m.	*	^{sec.} 35	^{sec.} ?	^{mm.} —	^{mm.} Small.	Origin distant.
„	11 45 57 p.m.	*	30	6.7	0.002	0.004	
24	1 33 55 a.m.	Slight.	55	13.3	0.003	0.031	
„	3 01 17 a.m.	*	40	?	—	0.003	Origin distant.
„	0 05 38 p.m.	Moderate.	75	6.3	0.044	0.780	Loud sound heard toward S.
25	6 49 10 p.m.	Slight.	235	99.0	0.061	0.097	Accompanied by sound.
26	3 52 10 p.m.	Do.	26	6.7	0.002	0.009	Do.
„	4 18 00 p.m.	*	30	?	—	Small.	Origin distant.
„	5 33 10 p.m.	*	30	?	—	Do.	Do.
27	3 40 56 p.m.	*	70	?	—	0.020	Origin distant.
28	4 10 00 a.m.	*	80	?	—	0.014	Do.
„	8 56 00 a.m.	*	40	?	—	0.002	Do.
29	1 27 30 a.m.	Slight.	60	8.4	—	0.028	Accompanied by sound.
„	3 04 28 a.m.	*	30	14.5	—	0.004	
„	1 23 57 p.m.	*	30	?	—	Small.	Origin distant.
„	7 51 54 p.m.	*	55	25.0	—	0.007	
„	7 55 35 p.m.	Slight.	40	9.6	—	0.018	
30	1 15 42 a.m.	*	30	7.9	—	0.009	
„	9 27 02 a.m.	*	40	23.0	—	Small.	
31	7 40 15 a.m.	*	40	9.7	—	0.006	
„	1 17 46 p.m.	Slight.	55	8.8	—	0.030	Accompanied by sound.
„	1 35 45 p.m.	*	50	12.5	—	0.017	
September.							
1	9 39 44 a.m.	Slight.	95	40.0	—	0.022	Accompanied by sound.
„	11 43 30 a.m.	Moderate.	220	79.0	0.032	0.150	Sound heard toward S.
2	0 53 23 a.m.	*	120	36.0	—	0.013	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion	
	September.						
2	h m s 3 35 12 p.m.	*	sec. 20	sec. ?	mm. —	mm. Small.	Origin distant.
„	3 43 25 p.m.	*	110	34.3	0.002	0.017	
„	4 26 30 p.m.	Moderate.	90	13.1	0.003	0.024	Loud sound heard toward S.
„	7 05 10 p.m.	*	70	12.3	—	0.016	
3	2 03 20 a.m.	Moderate.	140	10.6	0.012	0.150	Sound heard toward S.
4	7 32 30 a.m.	Slight.	30	6.9	—	0.006	Accompanied by sound.
„	8 49 35 a.m.	Do.	70	9.2	0.003	0.044	Do.
6	1 02 00 a.m.	*	60	?	—	0.007	Origin distant.
8	0 01 12 a.m.	*	60	?	—	0.002	Do.
9	11 35 17 p.m.	*	40	?	—	0.010	Do.
10	4 54 21 a.m.	*	40	?	—	0.004	Do.
11	4 33 38 p.m.	*	90	30.0	—	0.010	
„	7 52 10 p.m.	*	30	?	—	Small.	Origin distant.
„	10 16 20 p.m.	*	20	?	—	Do.	Do.
12	10 03 45 a.m.	*	50	?	—	Do.	Do.
„	11 36 25 a.m.	*	—	8.3	—	0.002	
13	5 36 15 p.m.	Slight.	70	7.4	0.003	0.017	Accompanied by loud sound.
14	2 44 05 a.m.	Do.	25	6.8	0.003	0.022	Accompanied by sound.
„	8 36 50 p.m.	*	60	8.4	—	0.003	
15	1 21 25 a.m.	*	40	?	—	0.002	Origin distant.
„	2 13 35 p.m.	Slight.	50	12.0	0.002	0.022	Accompanied by sound.
16	6 35 30 a.m.	*	40	14.6	—	0.002	
17	3 54 01 a.m.	*	60	?	—	0.004	Origin distant.
„	4 34 43 a.m.	*	30	?	—	0.003	Do.
„	4 58 54 p.m.	*	40	17.6	—	0.004	
„	9 03 00 p.m.	*	80	32.3	—	0.003	
„	9 46 30 p.m.	*	30	9.3	—	Small.	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	September.						
18	^{h m s} 10 17 20 a.m.	*	^{sec.} 80	^{sec.} 21.0	^{mm.} —	^{mm.} 0.018	
„	9 01 45 p.m.	*	120	39.0	—	0.006	
19	10 48 00 a.m.	*	60	?	—	0.007	Origin distant.
„	10 38 30 p.m.	*	20	7.8	—	0.010	
20	4 22 10 p.m.	Slight.	65	8.4	0.002	0.038	{ Loud sound of some duration heard toward S.
21	9 58 40 p.m.	*	40	?	—	0.002	Origin distant.
„	10 00 55 p.m.	Moderate.	120	9.7	0.250	0.860	No sound.
22	11 45 30 a.m.	*	70	?	—	0.011	Origin distant.
„	6 07 25 p.m.	*	120	40.2	0.006	0.024	
23	3 34 10 a.m.	*	25	10.0	—	0.002	
„	3 42 25 a.m.	*	25	?	—	0.004	Origin distant.
„	11 21 30 a.m.	*	30	?	—	0.007	Do.
„	4 42 30 p.m.	*	25	?	—	0.002	Do.
24	2 08 40 a.m.	Moderate.	85	7.8	0.031	0.210	Sound heard toward SW.
25	9 16 28 p.m.	Slight.	Short.	0.0	—	0.022	Accompanied by sound.
26	3 25 36 p.m.	Do.	70	9.0	0.017	0.636	{ Loud sound heard toward SW.
27	9 47 28 p.m.	*	120	24.0	0.006	0.025	
28	7 22 00 p.m.	Slight.	25	5.8	0.002	0.007	Accompanied by sound.
30	3 44 55 p.m.	*	70	?	—	0.014	Origin distant.
	October.						
1	6 18 00 a.m.	Slight.	25	7.6	—	0.013	
2	7 47 10 a.m.	*	40	6.6	—	0.006	
„	10 56 20 a.m.	Moderate.	160	10.0	0.097	0.580	
3	2 53 45 a.m.	Slight.	35	10.6	—	0.002	
„	4 12 25 p.m.	Do.	35	3.6	—	0.036	Accompanied by loud sound.
„	7 50 46 p.m.	Do.	60	9.1	0.014	0.026	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	October.						
	h m s		sec.	sec	mm.	mm.	
4	8 15 55 a.m.	*	Long.	—	—	—	Origin distant.
"	2 40 55 p.m.	Slight.	Short.	Short.	—	—	Accompanied by loud sound.
5	1 56 44 a.m.	*	60	14.7	—	0.017	
6	8 51 40 p.m.	Slight.	25	5.9	—	0.007	Accompanied by loud sound.
8	6 11 10 a.m.	*	50	18.0	—	0.002	
10	5 10 55 a.m.	*	180	88.0	0.007	0.017	
"	10 54 10 a.m.	Moderate.	145	9.2	0.061	0.430	Loud sound heard toward S.
"	11 10 55 a.m.	Slight.	30	?	—	0.020	
"	1 49 20 p.m.	Do.	60	?	—	0.039	Origin distant.
"	2 08 00 p.m.	Dp.	240	95.0	0.011	0.076	
"	2 28 20 p.m.	Do.	90	?	—	0.056	Origin distant.
"	2 36 10 p.m.	*	90	?	—	0.017	Do.
"	2 58 50 p.m.	*	120	?	—	0.020	Do.
"	3 22 10 p.m.	*	60	?	—	0.038	Do.
"	4 52 30 p.m.	*	40	?	—	Small.	Do.
"	8 51 15 p.m.	Slight.	90	39.0	—	0.038	Loud sound heard toward S.
"	9 34 35 p.m.	*	70	1.14	—	0.011	
"	9 46 40 p.m.	*	60	23.4	—	Small.	
11	9 13 05 a.m.	*	70	?	—	Do.	Origin distant.
"	3 43 18 p.m.	*	60	16.0	—	0.011	
12	8 06 00 a.m.	*	40	10.0	—	0.004	
13	9 27 15 p.m.	*	40	?	—	Small.	Origin distant.
14	11 54 20 a.m.	Moderate.	80	5.7	0.044	0.240	Accompanied by sound.
"	4 33 05 p.m.	Slight.	Short.	10.0	—	0.018	
15	6 46 35 a.m.	Do.	60	12.0	—	0.030	Accompanied by sound.
16	0 34 27 p.m.	*	60	15.1	—	0.011	
"	4 20 55 p.m.	*	60	?	—	Small.	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	October.						
17	^{h m s} 1 21 00 p.m.	*	^{sec.} 40	^{sec.} ?	mm. —	mm. 0.006	Origin distant.
"	4 53 10 p.m.	*	30	?	—	0.033	Do.
18	4 59 45 a.m.	*	40	?	—	0.003	Do.
"	5 00 50 a.m.	*	50	10.0	—	0.006	
"	5 04 55 a.m.	*	50	9.3	—	0.002	
"	9 54 05 p.m.	*	70	10.2	—	0.013	
19	9 10 20 a.m.	Moderate.	85	9.3	0.060	0.120	Accompanied by sound.
"	9 04 20 p.m.	*	50	?	—	0.004	Origin distant.
20	2 43 30 a.m.	*	60	?	—	0.017	Do.
"	1 42 10 p.m.	*	40	?	—	0.004	Do.
"	2 16 00 p.m.	*	100	43.0	—	0.011	
22	9 38 10 a.m.	*	75	?	—	0.018	Origin distant.
"	9 39 55 a.m.	*	60	?	—	0.018	Do.
"	11 42 30 a.m.	*	85	?	—	0.028	Do.
"	11 43 35 p.m.	*	60	14.4	—	0.031	
23	6 00 00 p.m.	*	40	8.9	—	0.012	
24	0 48 10 p.m.	Moderate.	180	50.0	0.008	0.058	
25	11 12 40 p.m.	*	100	?	—	0.004	Origin distant.
26	6 01 50 a.m.	*	90	?	—	0.003	Do.
27	1 29 25 a.m.	*	60	?	—	0.003	Origin distant.
28	6 47 15 p.m.	*	60	?	—	0.013	Do.
30	7 36 00 a.m.	*	60	8.3	0.006	0.013	
"	11 32 30 p.m.	*	60	?	—	0.003	Origin distant
31	1 02 40 p.m.	*	35	10.4	—	0.003	
	Novem- ber.						
1	2 01 50 p.m.	Moderate.	190	?	—	0.140	No sound. Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	November.						
	h m s		sec.	sec	mm.	mm.	
1	2 11 15 p.m.	Slight.	60	?	—	0.007	Accompanied by sound.
..	3 35 10 p.m.	*	70	?	—	0.007	Origin distant.
..	7 46 45 p.m.	Slight.	50	10.9	—	0.012	Accompanied by sound.
2	11 22 48 a.m.	Moderate.	110	12.9	0.073	0.190	No sound.
4	8 36 10 a.m.	Do.	80	11.4	0.019	0.120	Accompanied by sound.
5	2 12 40 a.m.	*	40	13.0	—	0.011	
..	3 32 50 p.m.	*	40	8.4	—	0.010	
8	11 11 20 p.m.	*	60	8.6	0.011	0.030	
9	5 56 00 a.m.	*	70	?	—	0.011	Origin distant.
..	7 19 50 p.m.	*	70	?	—	0.011	Do.
10	7 34 00 p.m.	Slight.	15	6.6	0.002	0.019	Accompanied by sound.
11	3 41 25 a.m.	*	60	19.7	—	0.015	
..	7 25 35 p.m.	Slight.	60	19.5	—	0.027	Accompanied by sound.
12	1 52 00 a.m.	Do.	80	10.6	0.007	0.071	Do.
..	8 53 10 a.m.	Do.	60	18.9	—	0.039	
16	10 28 30 p.m.	*	60	?	—	0.006	Origin distant.
19	0 49 50 a.m.	*	85	37.5	—	0.007	
..	2 51 24 a.m.	Slight.	50	4.5	0.003	0.044	Accompanied by loud sound.
..	6 08 05 p.m.	Do.	30	2.2	—	0.007	 sound.
20	8 19 55 a.m.	*	45	16.0	—	0.007	
22	1 02 00 a.m.	*	25	—	—	—	
..	4 27 50 a.m.	*	60	—	—	—	
23	0 04 00 a.m.	*	20	—	—	—	
..	0 11 00 a.m.	*	120	50.0	—	—	
..	7 30 10 a.m.	*	85	—	—	—	
..	3 34 20 p.m.	*	80	—	—	—	
24	6 31 20 a.m.	Slight.	50	15.9	—	0.050	Accompanied by sound.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
November.							
24	^{h m s} 8 29 00 p.m.	Slight.	^{sec.} 35	^{sec.} 12.5	^{mm.} —	^{mm.} 0.041	Accompanied by loud sound.
26	6 16 20 p.m.	Do.	70	11.1	0.006	0.044	" " sound.
27	0 34 10 p.m.	Do.	150	31.3	0.007	0.037	Do.
28	6 03 10 p.m.	Do.	40	8.3	—	0.018	Do.
29	8 05 10 a.m.	*	50	11.4	—	0.014	
"	11 45 55 p.m.	*	30	?	—	Small.	Origin distant.
30	10 31 00 p.m.	*	50	13.7	—	0.003	
December.							
2	2 15 45 p.m.	Slight.	85	24.0	—	0.028	Accompanied by sound.
"	11 27 10 p.m.	*	55	9.9	—	0.016	
3	1 40 45 a.m.	*	60	9.8	—	0.020	
"	0 40 55 p.m.	Slight.	80	17.2	—	0.022	Accompanied by sound.
"	1 46 40 p.m.	Do.	140	29.0	0.014	0.061	
"	9 02 20 p.m.	Do.	30	6.2	—	0.003	Accompanied by sound.
5	1 07 10 a.m.	*	35	9.5	—	0.002	
"	1 20 40 a.m.	*	100	23.0	0.007	0.032	
"	4 38 45 a.m.	*	120	52.0	—	0.010	
6	10 20 10 p.m.	*	70	23.2	—	0.006	
"	11 09 40 p.m.	*	35	11.2	—	0.013	
7	6 39 10 a.m.	Slight.	50	7.1	—	0.049	Accompanied by sound.
"	6 47 55 a.m.	*	40	7.3	—	0.013	
8	11 40 15 a.m.	*	60	11.0	—	0.010	
9	8 14 50 p.m.	Slight.	45	8.1	0.003	0.013	Sound heard toward S.
11	5 29 10 a.m.	*	80	22.4	—	0.010	
"	11 06 15 a.m.	*	60	?	—	Small.	Origin distant.
"	11 39 25 a.m.	*	75	?	—	0.006	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion.	
	December.						
11	^{h m s} 2 41 20 p.m.	*	sec. 30	sec. P	mm. —	mm. Small.	Origin distant.
12	5 01 45 a.m.	*	25	6.9	—	0.006	Sound only perceived.
14	5 48 30 p.m.	Slight.	50	8.4	—	0.016	Accompanied by sound.
16	11 25 36 a.m.	Do.	70	11.8	—	0.077	
"	1 26 50 p.m.	*	80	15.8	—	0.006	
17	10 58 00 a.m.	Slight.	70	9.4	—	0.004	
"	8 24 15 p.m.	*	50	8.0	—	0.011	
18	1 04 50 p.m.	*	Short.	Short.	—	Small.	Loud sound was perceived.
"	7 56 00 p.m.	*	Do.	Do.	—	Do.	Do.
19	4 10 30 a.m.	*	10	P	—	0.004	Origin distant.
21	2 09 20 a.m.	Slight.	45	6.7	—	0.010	Accompanied by sound.
"	5 20 30 a.m.	Do.	30	P	—	Small.	Origin distant.
"	8 16 08 a.m.	Do.	100	8.0	—	0.033	
23	7 57 40 a.m.	*	60	14.1	—	0.007	
"	11 38 05 a.m.	Moderate.	195	33.6	0.017	0.160	Accompanied by sound.
24	4 29 30 p.m.	*	50	17.5	—	0.010	
25	6 19 40 p.m.	Slight.	50	8.4	—	0.007	
"	6 42 50 p.m.	Do.	80	9.2	—	0.033	
26	3 40 20 a.m.	*	10	—	—	—	
"	6 45 00 a.m.	*	50	—	—	—	
"	11 04 30 a.m.	Slight.	35	7.0	—	—	
"	0 11 45 p.m.	Moderate.	240	12.0	—	0.158	Accompanied by sound.
"	2 38 25 p.m.	*	20	—	—	—	
"	7 10 20 p.m.	*	40	—	—	—	
27	0 50 50 p.m.	*	60	21.8	—	0.010	
"	9 06 30 p.m.	*	50	P	—	0.007	
28	2 03 25 a.m.	*	40	P	—	0.008	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	December.						
	h m s		sec.	sec.	mm.	mm.	
28	4 03 40 p.m.	*	120	52.0	—	0.022	
29	6 59 30 p.m.	*	40	?	—	Small.	Origin distant.
"	7 02 40 p.m.	*	20	?	—	Do.	Do.
30	7 52 10 p.m.	*	80	9.6(?)	—	0.030	Do.

Typical Diagrams. Typical diagrams are reproduced in Pls. I to V, as follows.

Plate.	Figure.	Date.	Time of Occurrence.	Intensity.	Remarks.
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Sharp Local Earthquakes.

I	1	April 6	^{h m s} 9 29 10 p.m.	Moderate.	{ Loud sound heard 5 or 6 sec. before the shock.
	2	July 27	1 36 15 a.m.	Do.	Accompanied by loud sound.
	3	June 11	11 50 10 p.m.	Do.	Do.
	4	" 7	6 12 30 a.m.	Do.	Do.
	5	" 27	3 17 10 a.m.	Slight.	Accompanied by sound.

Large Earthquakes.

II	6	September 21	10 00 55 p.m.	Moderate.	No sound.
	7	October 2	10 56 20 a.m.	Do.	Do.

Small Local Shocks.

III	8	September 2	4 26 30 p.m.	Moderate.	Accompanied by loud sound.
	9	April 6	11 33 40 p.m.	Unfelt.	
	10	May 26	2 00 25 a.m.	Slight.	Accompanied by sound.
	11	September 20	4 22 10 p.m.	Do.	.. loud sound.
	12	October 2	7 47 10 a.m.	Unfelt.	
	13	September 19	10 38 30 p.m.	Do.	

Earthquakes of some Distant Origin. (a)

IV	14	July 7	1 21 25 a.m.	Moderate.	No sound.
	15	November 1	2 01 50 p.m.	Do.	Do.
	16	June 12	5 17 30 p.m.	Do.	{ Sound heard 5 sec. before the shock.
	17	May 26	3 46 50 p.m.	Do.	{ Loud sound heard 3 sec. before the shock.
	18	October 10	1 49 20 p.m.	Slight.	

Plate.	Figure.	Date.	Time of Occurrence.	Intensity.	Remarks.
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Earthquakes of some Distant Origin. (b)

V	19	July	7	7 17 25 a.m.	Moderate.	Accompanied by sound.
	20	August	25	6 49 10 p.m.	Slight.	Do.
	21	June	7	{ 2 39 50 p.m. 2 40 20 "	{ Moderate. Slight.	Accompanied by loud sound.
	22	July	7	10 33 00 a.m.	Unfelt.	
	23	October	10	5 10 55 a.m.	Do.	
	24	June	27	1 09 30 a.m.	Do.	
	25	September	2	3 45 25 p.m.	Do.	

The characteristics of a sharp local shock are the shortness of the duration of the preliminary tremor, and the occurrence of the maximum vibration of the latter and the principal portion at the commencement of each of the respective phases. In the cases of the four *moderate* earthquakes of April 6, July 27, and June 11 and 7, (Figs. 1 to 4, Pl. I), which were each accompanied or preceded by a loud sound, the duration of the preliminary tremor varied between 5.6 and 7.9 sec., the maximum double amplitude in the principal portion being 0.190 to 0.490 mm. In the *slight* earthquake of June 27 (Fig. 5, Pl. I), the duration of the preliminary tremor was 12.1 sec., the maximum motion being 0.183 mm.

The two earthquakes of Sept. 21 and Oct. 2, (Figs. 6 and 7, Pl. II), which were larger than those above mentioned were, according to the report of the observers, not accompanied by sound.

Of the six small local shocks whose diagrams are given in Pl. III, that on Sept. 2, (Fig. 8), was accompanied by loud sound and was moderate in intensity, although its maximum motion was only 0.094 mm; the preliminary tremor having lasted 13.1 sec.

The *slight* earthquakes on May 26 and Sept. 20, (Figs. 10 and 11), were also accompanied by sound, which was loud in the case of the second shock. Of the remaining three insensible earthquakes, (Figs. 9, 12, and 13), those on Oct. 2 and Sept. 19 were extremely small.

Of the four *moderate* earthquakes (PL. VI), whose origins were at some distance from Tsukuba, those on July 7 and Nov. 1, (Figs. 14* and 15), are reported as having been accompanied by no sound. The other two shocks, which happened on June 12 and May 26, were each preceded by loud sound. The slight earthquake on Oct. 10 (Fig. 18) was similar to, but much smaller than, that on May 26 (Fig. 17).

The diagram of the earthquake of July 7 (Fig. 19), which was accompanied by sound, presents an appearance of two shocks happening in succession, the motion being comparatively large in the preliminary tremor, which was of a long duration and lasted 62 sec. In fact, this earthquake has been reported by the observers at Tsukuba as two distinct ones, whose intensities were *slight* and *moderate* respectively. The diagram of the earthquake of Aug. 25 (Fig. 20), indicates the similar peculiarity still more markedly; the motion in the preliminary tremor, which lasted 99 sec., being not much smaller than that in the principal portion. This earthquake was also reported as two separate ones, each of which was *slight* and was accompanied by sound. The latter circumstance is very interesting, as it gives support to the view that the earthquake sound occurs not only in the preliminary tremor, but also in the principal portion. The two unfelt earthquakes on July 7 and Oct. 10, (Figs. 22 and 23), are much similar in character to

* The zero-position of the recording pointer of the instrument suffered some displacement during the shaking.

the two shocks above mentioned. Fig. 21 represents, on the other hand, a case of two really distinct earthquakes one of which was *moderate* and the other *slight*, happening in quick succession. Finally, the two earthquakes on June 27 and Sept. 2 are examples of shocks of somewhat distant origin, whose preliminary tremor is small.

Duration of the preliminary tremor. The relative frequencies of the different lengths of the duration of preliminary tremor less than 40 sec., measured in the cases of 329 earthquakes, were as shown in the following table

Duration of Prel. Tremor.		Number of Earthquakes.	Duration of Prel. Tremor.		Number of Earthquakes.
sec.	sec.		sec.	sec.	
0.0—0.9		9	20.0—20.9		3
1.0—1.9		0	21.0—21.9		3
2.0—2.9		2	22.0—22.9		4
3.0—3.9		2	23.0—23.9		6
4.0—4.9		4	24.0—24.9		3
5.0—5.9		15	25.0—25.9		4
6.0—6.9		29	26.0—26.9		0
7.0—7.9		24	27.0—27.9		1
8.0—8.9		36	28.0—28.9		2
9.0—9.9		35	29.0—29.9		3
10.0—10.9		21	30.0—30.9		5
11.0—11.9		18	31.0—31.9		1
12.0—12.9		13	32.0—32.9		3
13.0—13.9		11	33.0—33.9		1
14.0—14.9		11	34.0—34.9		1
15.0—15.9		8	35.0—35.9		3
16.0—16.9		9	36.0—36.9		3
17.0—17.9		11	37.0—37.9		2
18.0—18.9		9	38.0—38.9		0
19.0—19.9		12	39.0—39.9		2

The number of cases, in which the duration of the preliminary tremor was over 40 sec., is 24, as follows:—

Duration of the Prel. Tremor.	40 sec.	58 sec.
	40.2	60
	41	62
	41	62
	43	63
	46	65
	49.3	69
	50	79
	50	88
	52	95
	52	99
	54	114

As graphically illustrated in Fig. 26, Pl. VI, the duration of the preliminary tremor most frequently occurring was between 6 and 10 sec., the number of the corresponding earthquakes being equivalent to the two-thirds of all the others. The relation between the duration of the preliminary tremor and the corresponding frequency of earthquakes will be of course different for different places of observation.

Number of sensible shocks. The total number of the sensible shocks was 171, while that of mere sounds (not accompanied by perceptible earth movement) was 12, as follows.

Month.	Sensible and Insensible Eqkes.	Number of		
		Sensible Eqkes.	Mere Sounds.	Sensible Eqkes, accompanied by Sound.
I	24	12	2	10
II	31	17	5	18
III	24	14	0	13
IV	26	7	1	7
V	27	8	0	5
VI	50	15	0	14
VII	67	21	1	17
VIII	48	11	0	9
IX	49	15	0	14
X	57	18	0	9
XI	35	16	0	13
XII	49	17	3	12
Sum	487	171	12	141

Thus the number of the sensible earthquakes, (including the cases of mere sounds), was 183, so that such shocks occurred at Tsukuba on the average once nearly every two days. The number of the insensible shakings was 304.

Earthquake sounds. At Tsukuba, earthquake sounds are perceived very often, which may be likened to the noises of distant thunders or of a wagon passing over a wooden bridge, those like the rushing of winds being comparatively rare. The monthly numbers of the sensible shocks accompanied by sound, including the cases of sounds without sensible motion, are given in the last column of the above table. From the latter it will be seen that earthquake sounds occurred in 141 cases, or in 77% out of the 183 sensible shocks. It is possible that all of the latter, or nearly so,

are found to be accompanied by more or less sound, when very attentively observed.

There were 27 cases, in which the direction of the sound was noted, as follows:—

{	Sound heard toward the South	17 cases.
	„ South-West	9 „
	„ South-East.....	1 „

The resultant, or mean, direction was thus South-West by South. That the sounds were perceived as coming from this quarter may be due to the fact that the lower part of the southern slope of the mountain, where the town of Tsukuba is situated, is horse-shoe shaped and opens in the same direction to the low plane.

In a majority of cases the sound was first perceived, followed immediately or a few seconds later by the tremblings of the ground, as in the following examples.

Eqke of May 26.....{Duration of Prel. tremor=19.4 sec.
Sound heard 3 sec. before the shock.

Eqke of June 12.....{Duration of Prel. tremor=18.4 sec.
Sound heard 5 sec. before the shock.

It is probable that the commencement of the sound is generally at the same instant as that of the preliminary tremor, whose earlier part may often be insensible while the sound is perceptible. This explanation can not, however, be applied to the following two cases, provided the report of the observers be accurate:—

Eqke of April 6.....{Duration of Prel. tremor=6.7 sec.
Sound heard 5 or 6 sec. before the shock.

Eqke of June 11..... { Duration of Prel. tremor=5.6 sec.
 { Sound heard 3 sec. before the shock.

In each of these two shocks, which were *moderate* in intensity, the motion at the commencement of the preliminary tremor was quite large and perfectly sudden. Hence it seems impossible that sound should be heard a few seconds prior to the arrival of the sensible motion, unless the vibrations of the ground giving rise to the sound phenomena form a sort of an *ultra* preliminary tremor and are so extremely minute that the seismograph used could give no visible trace. Such a supposition may not be entirely wrong, since there are cases of loud sounds hardly accompanied by any movement.

Earthquake sound and duration of preliminary tremor.

The numbers of sensible earthquakes and of those accompanied by sounds, for the different lengths of the preliminary tremor, are given in the following table.

Duration of Prel. Tremor.	Total Number of Sensible Earthquakes= <i>e</i> .	Eqkes accompanied by Sound*= <i>s</i>	Ratio : $\frac{s}{e}$
(i) sec. sec. 0—5.0	18	18	100 %
(ii) 5.1—10.0	77	66	86
(iii) 10.1—15.0	35	28	80
(iv) 15.1—20.0	20	16	80
(v) 20.1—25 0	5	4	80
(vi) >25.1	18	10	56
Sum : (i) to (v)	155	132	85

(* Including the cases of mere sound.)

Thus it will be observed that the sensible earthquakes of near origin of the duration of the preliminary tremor under 5 sec., were invariably accompanied by sound. The percentage number of the more distant shocks remained practically constant for the duration of the preliminary tremor between 5 and 25 sec., varying only between 86 and 80%, with the mean value of 85%. Even for the earthquakes of the duration of the preliminary tremor over 25 sec., the sound was by no means uncommon, the frequency amounting to 56%.

Distant earthquakes accompanied by sounds. Among the 183 sensible earthquakes, there were ten, which were accompanied by sounds, and the duration of whose preliminary tremor was longer than 25 sec., as follows.

Date.		Intensity.	Duration of Prel. Tremor.	Maximum Motion.
March	21	Slight.	^{sec.} 36.0	^{mm.} 0.020
June	10	Do.	36.4	0.042
July	7	Moderate.	62.0	0.173
Do.	9	Do.	29.3	0.150
August	25	Slight.	99.0	0.097
September	1	Do.	40.0	0.022
Do.		Moderate.	79.0	0.150
October	10	Slight.	39.0	0.038
November	27	Do.	31.3	0.037
December	23	Moderate.	33.6	0.160

In these 10 earthquakes, the duration of the preliminary tremor varied between 29.3 and 99.0 sec., which correspond respectively

to the epicentral distances of about 250 and 760 km; the maximum (EW component) motion in the principal portion varying between 0.020 and 0.173 mm. It is probable that even an earthquake at an epicentral distance of 1,000 km is able, when of a sufficient intensity, to produce sound phenomena at Tsukuba or any other district composed of hard rocks.

Earthquakes accompanied by loud sound. There were 35 cases in which the shock was accompanied by loud sound. The elements of motion in these earthquakes, arranged according to the length of the duration of the preliminary tremor, were as in the following table; the maximum movements in the preliminary tremor and the principal portion being denoted by $2a'$ and $2a$ respectively.

Date.		Duration of Prel. Tremor.	Intensity.	Max. Motion in Prel. Tremor = $2a'$	Max. Motion in Princ. Portion = $2a$
		sec.		mm.	mm. (No. motion indicated)
Jan.	25	0.0	Unfelt	—	—
Feb.	7	0.0	Slight	—	0.072
Oct.	4	(short)	Do.	—	Small
"	18	(Do.)	Unfelt	—	Do.
"	"	(Do.)	Unfelt	—	Do.
Aug.	20	2.5	Slight	—	0.022
Oct.	3	3.6	Do.	—	0.036
Nov.	19	4.5	Do.	0.003	0.044
July	12	4.7	Unfelt	0.002	0.004
April	30	4.9	Slight	—	0.036
"	27	5.4	Do.	0.004	0.021
Jan.	5	5.6	Do.	0.004	0.027
June	11	5.6	Moderate	0.066	0.230

Date.		Duration of Prel. Tremor.	Intensity.	Max. Motion in Prel. Tremor = $2a'$	Max. Motion in Princ. Portion = $2a$
		sec.		mm.	mm.
Oct.	6	5.9	Slight	—	0.007
June	7	6.1	Do.	0.032	0.190
July	26	6.2	Do.	0.016	0.073
Aug.	24	6.3	Moderate	0.044	0.770
April	6	6.7	Do.	0.093	0.490
July	29	6.9	Slight	—	0.060
June	6	7.0	Moderate	0.013	0.106
July	27	7.9	Do.	0.039	0.340
Sept.	13	7.4	Slight	0.003	0.017
"	20	8.4	Do.	0.002	0.038
April	13	9.0	Do.	0.018	0.064
Sept.	26	9.0	Do.	0.017	0.056
July	9	9.1	Do.	—	0.049
Oct.	3	9.1	Do.	0.014	0.026
"	10	9.2	Moderate	0.061	0.430
May	9	11.0	Do.	0.051	0.204
Nov.	24	12.8	Slight	—	0.041
Sept.	2	13.1	Moderate	0.006	0.094
June	26	13.3	Slight	0.008	0.039
"	7	17.7	Moderate	0.027	0.093
May	26	19.4	Do.	0.043	0.160
Oct.	10	39.0	Slight	—	0.038

Thus it will be seen that loud sounds occurred most frequently in the earthquakes, whose preliminary tremor lasted less than about 9 or 10 sec., corresponding to an epicentral distance of about 100 km. In three cases, the duration of the preliminary tremor was much longer, being from 17.7 to 39.0 sec. Again, of the 35

earthquakes tabulated above, 10 were *moderate*, 21 were *slight*, and the remaining 4 were unfelt shocks; each of the last having a very short preliminary tremor or apparently none whatever. The maximum motion in the preliminary tremor ($=2a'$) varied between 0.002 and 0.093 mm, and that in the principal portion ($=2a$) between 0.004 and 0.770 mm.* It is thus seen that the intensity of motion is not a necessary factor in the production of the sound phenomena, although a violent earthquake will always be accompanied by a very loud sound.

Ratio of maximum motion in preliminary tremor to that in principal portion. The maximum movements in the preliminary tremor and principal portion of the 7 sharp local shocks, whose diagrams are given in Pls. I and II, were as follows.

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor $=2a'$.	Max. Motion in Princ. Portion $=2a$.	Ratio: $\frac{2a}{2a'}$
		sec.	mm.	mm.	
April	6	6.7	0.093	0.490	5.3
July	27	7.9	0.039	0.340	8.7
June	11	5.6	0.066	0.220	3.3
"	7	6.1	0.032	0.190	5.9
"	27	12.1	0.028	0.183	6.5
Sept.	21	9.7	0.250	0.860	3.4
Oct.	2	10.0	0.097	0.580	6.0
Mean					5.6

Thus the motion in the preliminary tremor increased generally

* Excepting a few cases in which the motion was immeasurably small.

with the strength of the shaking and was on the average $1/5.6$ of that in the principal portion. Hence it is likely that a violent destructive shock of near origin begins abruptly with quite large vibrations, so that its preliminary tremor may be much stronger than the principal portion of an ordinary earthquake.

In the following table, I give the $2a'$ and $2a$ in the 19 earthquakes of moderate intensity, whose duration of the preliminary tremor was under 20 sec. and whose absolutely greatest motion ($2a$) was over 0.1 mm; the shocks being arranged according to the magnitude of the latter element of motion.

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor = $2a'$.	Max. Motion in Princ. Portion = $2a$.	Ratio: $\frac{2a}{2a'}$
		sec.	mm.	mm.	
Aug.	24	6.3	0.044	0.780	17.7
Oct.	10	9.2	0.061	0.430	7.0
„	14	5.7	0.044	0.240	5.5
Jan.	26	11.0	0.028	0.220	7.9
Sept.	24	7.8	0.031	0.210	6.8
May	9	11.0	0.051	0.204	4.0
June	18	13.2	0.023	0.190	8.3
Nov.	2	12.9	0.073	0.190	2.6
June	12	18.4	0.054	0.190	3.5
<i>Mean</i>					7.0
Feb.	17	14.1	0.027	0.180	6.7
March	4	9.0	0.022	0.170	7.7
May	26	19.4	0.043	0.160	3.7
April	24	9.0	0.017	0.153	9.0

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor = $2a'$	Max. Motion in Princ. Portion = $2a$	Ratio: $\frac{2a}{2a'}$
		sec.	mm.	mm.	
Sept.	3	10.6	0.012	0.150	12.5
Feb.	7	17.0	0.036	0.120	3.3
July	19	9.3	0.022	0.120	5.4
Oct.	19	9.8	0.060	0.120	2.0
July	23	19.0	0.031	0.107	3.4
June	6	7.0	0.013	0.106	8.1
Mean					6.2

Dividing the 19 earthquakes tabulated above into two groups, of $2a > 0.19$ mm and of $2a < 0.18$ mm, the average values of the ratio $2a/2a'$ come out to be 7.0 and 6.2 respectively; the variation of this ratio with the $2a$ being apparently not significant. The mean value of this ratio deduced from the preceding tables is 6.3.

Finally, confining our attention to those sensible earthquakes, which were not accompanied by sound, the mean value of the ratio of $2a/2a'$ is found to be 5.7. This is not materially different from the mean value, namely, 7.0, of the corresponding quantity for those shocks accompanied by loud sound (page 35).

Least limit of sensible motion. In the sensible earthquakes, unaccompanied by sound, the maximum motion $2a$ was usually greater than 0.013 mm, there being only three cases in which it was less than this limit. With the earthquakes accompanied by sound, however, the limit of sensible motion was still lower, due probably to the predominance of quick vibrations in

these shocks; there being 14 cases in which the maximum motion $2a$ was less than 0.01 mm, as follows:—

mm									Number of Equea.
$2a = 0.010$	..	...	...	...	...	...	...	...	3
$2a = 0.009$	...	...	...	...	...	...	...	...	1
$2a = 0.008$	...	...	...	...	...	...	...	...	2
$2a = 0.007$	...	...	...	...	...	...	...	...	5
$2a = 0.006$	...	...	...	...	...	...	...	...	1
$2a = 0.004$	...	...	...	...	...	...	...	...	1
$2a = 0.003$	...	...	...	...	...	...	...	...	1

Making an allowance for the possible error in the measurement of very small movements, and provisionally excluding the last three cases, we may take the double amplitude of **0.007** mm as the limit of sensible vibration, the EW component motion alone being taken into account. Assuming the corresponding NS component to be of an equal range, the resultant double amplitude of the sensible motion would be about **0.01** mm. This latter value is to be regarded as the lowest limit of the earthquake motion which is intense enough to be felt without instrumental aid by people living in wooden houses at a quiet rocky district, where the earth vibrations are rapid.

The result here obtained is in accordance with that relating to the small vibrations of the ground caused artificially by an oil engine, etc. (See my paper, A Horizontal Tremor Recorder, in the *Publications*, No. 18). For Tokyo, the intensity of the lowest limit of the sensible motion was found to be an acceleration of 17 mm per sec. per sec. This is to be regarded as defining the feeblest earthquake motion sensible to people living in a large city or some other place where there is much disturbances arising

from traffic, the working of steam engines, dynamos, etc. (See the *Publications*, No. 11.)

Conclusion. One of the principal objects in making the seismographic observations at Tsukuba was the comparison of the results there obtained with those simultaneously obtained in Tokyo and Mito, to determine thereby the accurate positions of the origins of the different local shocks, and also the relation between the epicentral distance and the duration of the preliminary tremor for near earthquakes. Further discussions on the Tsukuba observations in these connections are reserved for a future occasion. The instrumental study of the minute vibrations giving rise to sound phenomena is of course very important.

Tokyo, March 1908.

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 1.

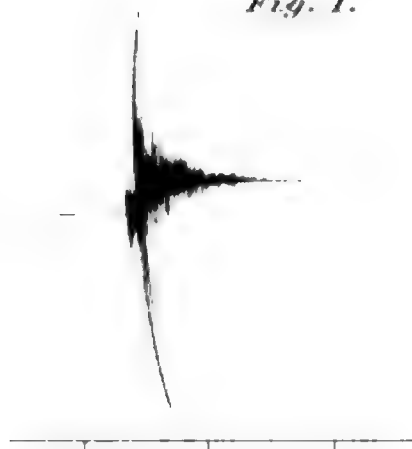


Fig. 3.

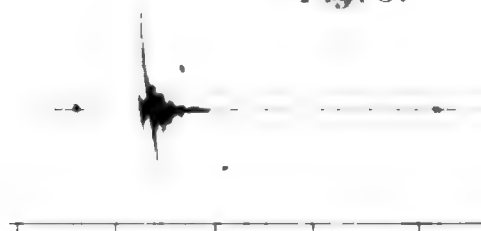


Fig. 4.



Fig. 2.

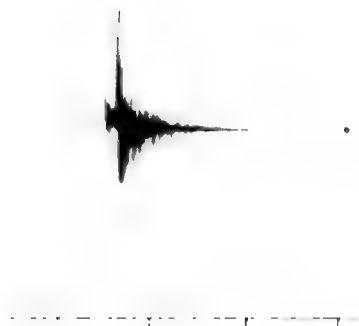
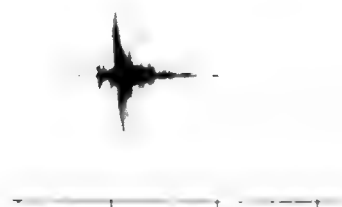


Fig. 5.



- | | | |
|---------|--------------------------|---|
| Fig. 1. | April 6; 9h 29m 10s P.M. | { Moderate. Loud Sound heard
5 or 6 sec. before the shock. |
| „ 2. | July 27; 1 38 15 A.M. | Moderate. Accompanied by loud sound. |
| „ 3. | June 11; 11 50 10 P.M. | Do. |
| „ 4. | „ 7; 6 12 30 A.M. | Do. |
| „ 5. | „ 27; 3 17 10 A.M. | Slight. Accompanied by sound. |

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time: 1 interval=1 minute.

Fig. 6.
Sept. 21:10^h00^m55^s Pm.



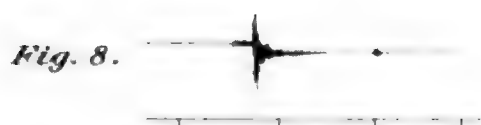
Fig. 7.
Oct. 2:10^h56^m20^s Am.



Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

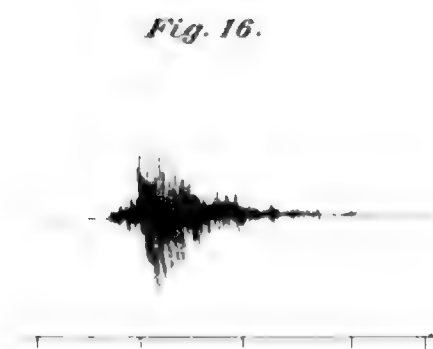
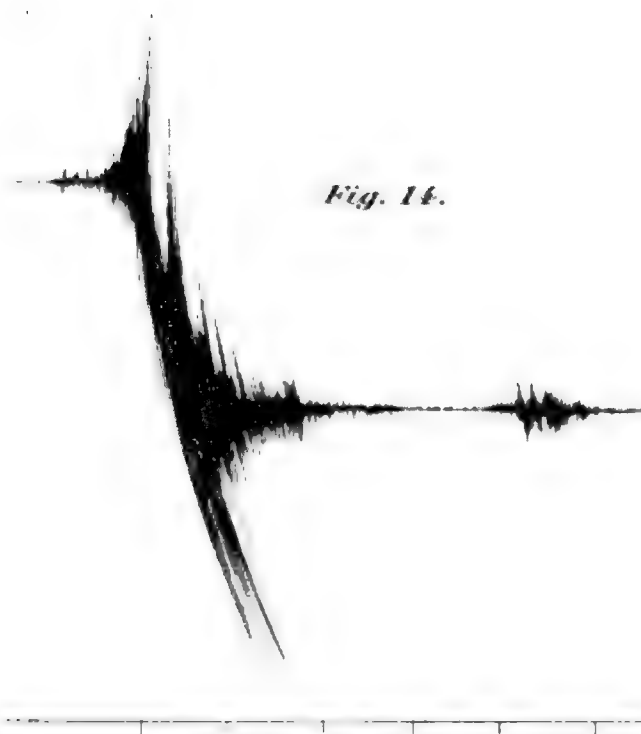


- | | | | | | |
|---------|-----------|------------|------|-----------|----------------------------|
| Fig. 8. | Sept. 2; | 4h 26m 30s | P.M. | Moderate. | Accompanied by loud sound. |
| „ 9. | April 6; | 11 33 40 | P.M. | Unfelt. | |
| „ 10. | May 26; | 2 00 25 | A.M. | Slight. | Accompanied by sound. |
| „ 11. | Sept. 20; | 4 22 10 | P.M. | Slight. | Accompanied by loud sound. |
| „ 12. | Oct. 2; | 7 47 10 | A.M. | Unfelt. | |
| „ 13. | Sept. 19; | 10 38 30 | P.M. | Unfelt. | |

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

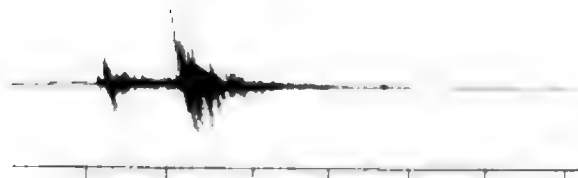
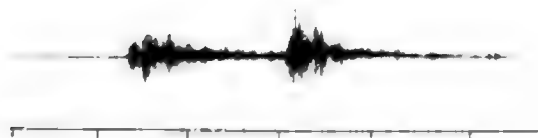
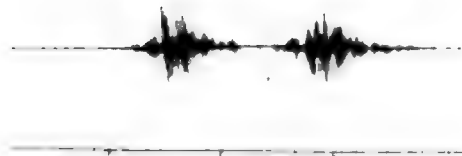


- Fig. 14. July 7; 1h 21m 25s A.M. Moderate. No sound.
.. 15. Nov. 1; 2 01 50 P.M. Moderate. No sound.
.. 16. June 12; 6 17 30 P.M. { Moderate. Sound heard
 { 5 sec. before the shock.
.. 17. May 26; 3 46 50 P.M. { Moderate. Loud sound heard
 { 3 sec. before the shock.
.. 18. Oct. 10; 1 49 20 P.M. Slight.

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

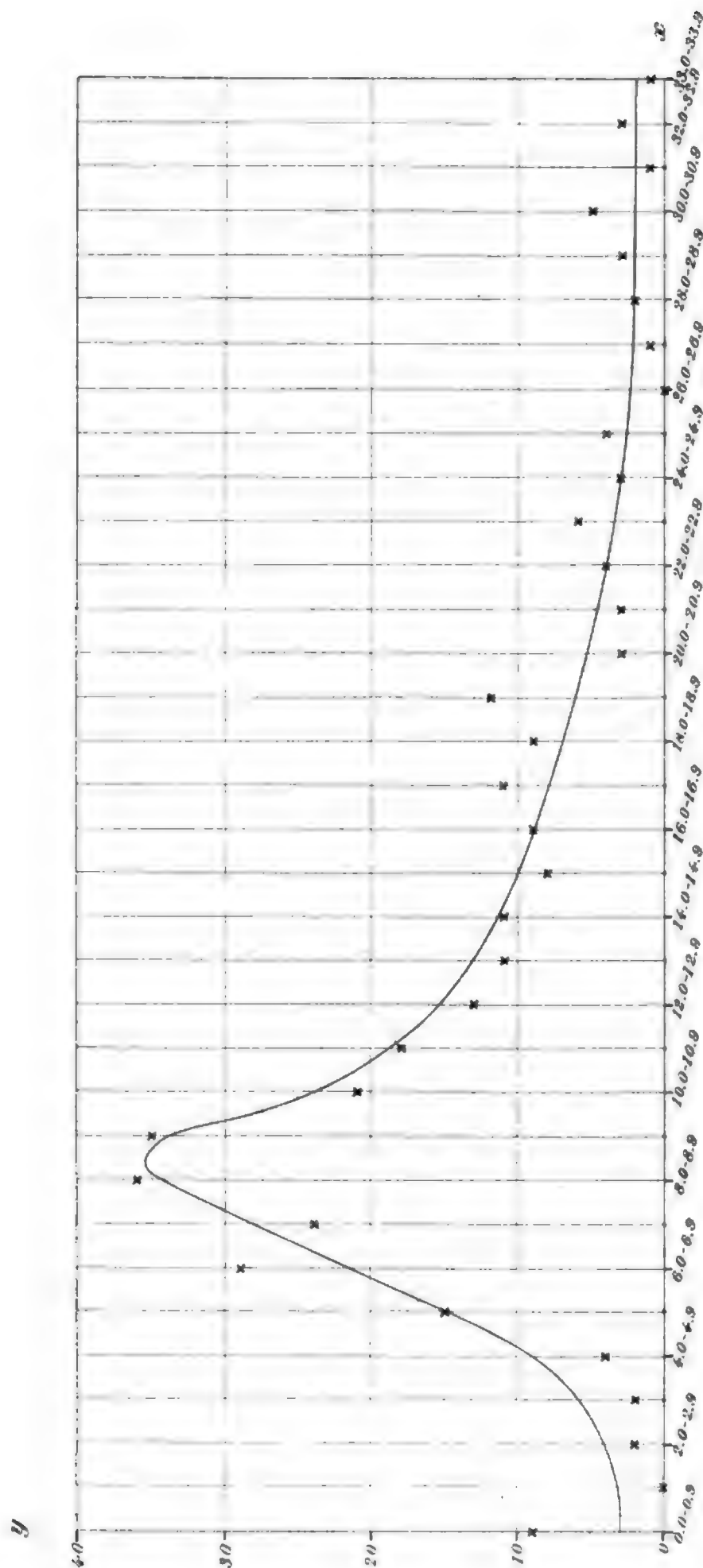
Fig. 19.*Fig. 22.**Fig. 20.**Fig. 23.**Fig. 24.**Fig. 21.**Fig. 25.*

- Fig. 19. July 7; 7h 17m 25s A.M. *Moderate.* Accompanied by sound.
 „ 20. Aug. 25; 6 49 10 P.M. *Slight.* Accompanied by sound.
 „ 21. June 7; { 2 39 50 P.M. { *Moderate.* Accompanied by loud sound.
 { 2 40 20 „ { *Slight.*
 „ 22. July 7; 10 38 00 A.M. *Unfelt.*
 „ 23. Oct. 10; 5 10 55 A.M. *Do.*
 „ 24. June 27; 1 09 30 A.M. *Do.*
 „ 25. Sept. 2; 3 48 25 P.M. *Do.*

Fig. 26. Relative Frequencies of the Earthquakes of different lengths
of the Duration of the Preliminary Tremor.

Pl. VI.

x = Duration of the Preliminary Tremor, in second.
 y = Number of the Earthquakes, the duration of whose preliminary tremor is equal to x .



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Earthquake Investigation Committee

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PUBLICATIONS OF THE EARTHQUAKE INVESTIGATION
COMMITTEE. NO. 22. SECTION B, ART. I.

Strains produced by Surface Loading over a Circular Area with Applications to Seismology.

By

H. NAGAOKA, *Rigakuhakushi*.

Member of the Earthquake Investigation Committee.

With Plates I-III.

§ 1. The problem dealing with the strains of an isotropic elastic solid, bounded on one side by an infinite plane, was treated by Bousinesq and Cerruti. The former has published a series of researches on the allied subject in his treatise "Applications du Potentiel," in which full information of the problem in its varied aspects is to be obtained. A separate chapter is devoted to problems dealing with the strains produced by a vertical pressure applied over a circular area on the bounding horizontal plane, but unfortunately only a few particular cases of strains are worked out. Those who are interested in seismology may find it serviceable to have an approximate solution of the problem concerning the strain of the earth's crust, when there is surface loading, which may be likened to atmospheric pressure or to weight of rainfall exerted over a circular portion of the surface, in order to deduce the strains arising therefrom and thus obtain in some measure indications of the surface deformations due to the said natural agencies. With this object in view, interesting applications to seismology have already been made by Chree;* he discussed the influence of surface loading over a rectangular area and calculated the deviations

* Chree, Phil. Mag. **43**, 173, 1897.

of the vertical and the tilting arising from it. A further extension of the problem to surface loading over a circular area is desirable, because the region of low or high pressure, as it is actually observed on the earth's surface, more resembles a circle than a rectangle. Moreover the loading is never uniform, so that the investigation of the problem of heterogeneous loading is not without interest. If the solution for an imperfect elastic solid, and for solids distributed in different strata were possible, the approximation to the actual problem as regards seismology would be of great value. The mathematical difficulty is however almost insurmountable, so that we are at present compelled to relinquish the attempt and satisfy ourselves with the solution for isotropic bodies.

Seismologists are familiar with the tremors associated with the change in the conditions of the atmosphere, sometimes in places quite outside the domain of low or high pressure. The question naturally arises how far from the place of surface loading the strain is appreciable, and how it depends on the extent of the stressed surface. Unfortunately the statical effect is generally difficult to observe, but the existence of the tremors itself indicates that the strain caused by the loading gives rise to elastic disturbance, calling forth free vibrations, which are presumably determined by the contour and geological structure of the region surrounding the place of observation. The surface wave thus called forth by distant surface loading is rather difficult of treatment, but we may obtain a crude idea from the calculation of the statical effect how far the influence of the stress is to be traced.

§ 2. Taking xy -coordinate plane as horizontal and z -axis vertically downwards, the components of elastic displacements u , v , w at point xyz in an isotropic elastic medium extending in positive direction of z axis, are given by

$$(1) \begin{cases} u = -\frac{1}{4\pi\mu} \frac{\partial^2}{\partial x \partial z} \int r dP - \frac{1}{4\pi(\lambda+\mu)} \frac{\partial}{\partial r} \int \log(z+r) dP \\ v = -\frac{1}{4\pi\mu} \frac{\partial^2}{\partial y \partial z} \int r dP - \frac{1}{4\pi(\lambda+\mu)} \frac{\partial}{\partial y} \int \log(z+r) dP \\ w = -\frac{1}{4\pi\mu} \frac{\partial^3}{\partial z^3} \int r dP + \frac{2\lambda+3\mu}{4\pi\mu(\lambda+\mu)} \int \frac{dP}{r} \end{cases}$$

where λ, μ are Lamé's constants, and the integration with respect to pressure P at point x', y', o , extends over the stressed area. The radius vector r is given by

$$r^2 = (x-x')^2 + (y-y')^2 + z^2$$

Since

$$\frac{\partial r}{\partial z^2} = \frac{1}{r} - \frac{z^2}{r^3}.$$

the vertical displacement on the horizontal plane is given by

$$w_0 = \frac{\lambda+2\mu}{4\pi\mu(\lambda+\mu)} \int \frac{dP}{r} \quad (2)$$

and the horizontal displacement for loading over a circle amounts to

$$U = -\frac{1}{4\pi(\lambda+\mu)} \int \frac{1}{r} \frac{\partial r}{\partial a} dP \quad (3)$$

where $a^2 = x^2 + y^2$, the centre of the circle being taken for the coordinate origin.

§ 3. For the calculation of the strain due to stress over a circular area, we shall have to use the following notations.

R : radius of the circle.

a : distance of the centre of the circle from the point Q under consideration (x, y, o) .

ρ : distance of surface point Q' (x', y', o) from the centre of the circle.

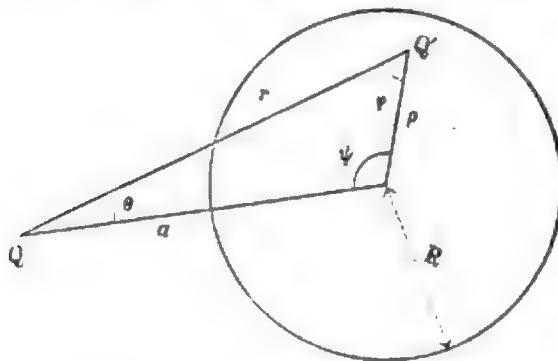
r : radius vector from the point on the surface at which the strain is sought.

θ : angle between r and a .

φ : angle subtended by a at the point Q' (x', y', o) .

ψ : angle subtended by r at the centre.

The accompanying figure will show these quantities at a glance.



§ 4. Uniform Pressure over a Circular Area.

We have to consider the present problem in two aspects; (1) when the point Q under consideration is outside the stressed circle, (2) when the the point is inside the circle.

Let the pressure per unit area be denoted by p_0 , then $dp = p_0 \rho d\rho d\psi$, and since

$$r^2 = a^2 + \rho^2 - 2a\rho \cos \psi,$$

$$(4) \quad U = -\frac{1}{4\pi(\lambda + \mu)} \int \frac{1}{r} \frac{\partial r}{\partial a} dP = -\frac{p_0}{2\pi(\lambda + \mu)} \int_0^R \int_0^\pi \frac{(a - \rho \cos \psi) \rho d\rho d\psi}{a^2 + \rho^2 - 2a\rho \cos \psi}$$

The integral

$$\begin{aligned} \int_0^\pi \frac{(a - \rho \cos \psi) d\psi}{a^2 + \rho^2 - 2a\rho \cos \psi} &= \frac{\pi}{2a} - \frac{\rho^2 - a^2}{2a} \int_0^\pi \frac{d\psi}{a^2 + \rho^2 - 2a\rho \cos \psi} \\ &= \frac{\pi}{a} \quad \text{for } a > \rho \\ &= 0 \quad \text{" } a < \rho \end{aligned}$$

Thus when the point Q lies inside the circle, we have to divide the integral into two parts

$$\int_0^R = \int_0^a + \int_a^R$$

of which the last part vanishes.

Consequently we obtain

$$(5) \quad \begin{cases} U = -\frac{p_0 R^2}{4(\lambda + \mu)a} & \text{for an external point} \\ U = -\frac{p_0 a}{4(\lambda + \mu)} & \text{,, ,, internal point.} \end{cases}$$

For positive pressure, the displacement tends towards the centre of the circle, and for negative pressure from it. For an external point, the horizontal displacement is directly proportional to the compressed area, and inversely proportional to the distance from the centre; for an internal point, it is simply proportional to the distance, so that the horizontal component is maximum at the periphery of the circle of pressure. Fig. 1. shows the graph of the displacement.

The vertical displacement is given by (2) in the form

$$(6) \quad w_0 = \frac{\lambda + 2\mu}{4\pi\mu(\lambda + \mu)} p \iint dr d\theta$$

But $\rho^2 = a^2 + r^2 - 2ar \cos \theta$ and $\sin \theta = \frac{\rho}{a} \sin \varphi$, consequently

$$dr = \frac{\rho d\rho}{\sqrt{\rho^2 - a^2 \sin^2 \theta}}$$

$$d\theta = \frac{\rho}{a} \frac{\cos \varphi}{\sqrt{1 - \frac{\rho^2}{a^2} \sin^2 \varphi}} d\varphi$$

Thus

$$(7) \quad \frac{2\pi\mu(\lambda + \mu)}{\lambda + 2\mu} w_0 = \frac{p_0}{a} \int_0^\pi \int_0^\pi \frac{\rho d\rho d\varphi}{\sqrt{1 - \frac{\rho^2}{a^2} \sin^2 \varphi}} \text{ for an external point.}$$

At an internal point, we have to divide the circle into two concentric circles, such that the point Q lies on the periphery of the internal circle. The displacement w_0 consists of two parts w_0' and w_0'' , of which

$$(7.) \quad \begin{cases} \frac{2\pi\mu(\lambda+\mu)}{\lambda+2\mu} w_0' = \frac{p_0}{a} \int_0^a \int_0^\pi \frac{\rho \, d\rho \, d\varphi}{\sqrt{1 - \frac{\rho^2}{a^2} \sin^2 \varphi}} \\ \frac{2\pi\mu(\lambda+\mu)}{\lambda+2\mu} w_0'' = p_0 \int_a^R \int_0^\pi \frac{d\rho \, d\varphi}{\sqrt{1 - \frac{\rho^2}{a^2} \sin^2 \varphi}} \end{cases}$$

and $w_0 = w_0' + w_0''$ for an *internal* point

To evaluate (7), let us put $\frac{\rho}{a} = \kappa$, then

$$\int_0^R \int_0^\pi \frac{\rho \, d\rho \, d\varphi}{\sqrt{1 - \frac{\rho^2}{a^2} \sin^2 \varphi}} = \int_0^R K \rho \, d\rho = a^2 \int_0^{\frac{R}{a}} K \kappa \, d\kappa$$

where K stands for a complete elliptic integral of the first kind. Using the wellknown formula

$$K \kappa \, d\kappa = d\left(\kappa \kappa'^2 \frac{\partial K}{\partial \kappa}\right)$$

$$\int_0^{\frac{R}{a}} K \kappa \, d\kappa = -k'^2 K(k) + E(k)$$

where E is an elliptic integral of the second kind and $k = \frac{R}{a}$,

$$k' = \sqrt{1 - \frac{R^2}{a^2}}.$$

Thus

$$(8) \quad w_0 = \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} p_0 a \{ E(k) - k'^2 K(k) \}; \text{ for an external point.}$$

On the periphery $\frac{R}{a} = 1$, and $E(1) = 1$; thus,

$$w_0 = \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} p_0 a.$$

At an *internal* point

$$\frac{2\pi\mu(\lambda+\mu)}{\lambda+2\mu} w_0' = 2\mu_0 a$$

and

$$\begin{aligned}\frac{2\pi\mu(\lambda+\mu)}{\lambda+2\mu}w''_0 &= p_0 \int_0^\pi \int_a^R \frac{d}{d\rho} (\sqrt{\rho^2 - a^2 \sin^2 \varphi}) d\rho \\ &= 2p_0 (RE(k) - a) \quad \text{where } k = \frac{a}{R}.\end{aligned}$$

Thus

$$(8_a) \quad w_0 = \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} p_0 RE(k) \quad \text{for } R > a.$$

The two expressions (8) and (8_a) coincide when $R=a$. The vertical displacement is greatest at the centre of the circle of pressure, and gradually decreases towards the periphery, but after passing out of the stressed area, the rate of diminution becomes extremely slow and ultimately vanishes in an asymptotic manner. Fig. 2 shows the amount of depression diagrammatically. These figures will better illustrate the general features of the horizontal and vertical displacements at a glance than a mere inspection of the mathematical formulas will show.

It may not be superfluous to give expressions for w_0 in terms of Weierstrass's notations. An easy calculation shows that

$$\begin{aligned}w_0 &= \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} p_0 a \frac{(\eta_1 + e_1 \omega_1)}{\sqrt{e_1 - e_3}} \quad \text{where } k = \frac{R}{a} \\ &\quad a \geq R \\ w_0 &= \frac{\lambda+2\mu}{\pi\mu(\lambda+\mu)} p_0 R \left(\frac{\eta_1 + e_1 \omega_1}{\sqrt{e_1 - e_3}} \right) \quad \text{where } k = \frac{a}{R} \\ &\quad R \geq a\end{aligned}$$

For the purposes of numerical calculation, it is convenient to have these expressions transformed into θ -functions, in order that we may employ q -series with advantage.

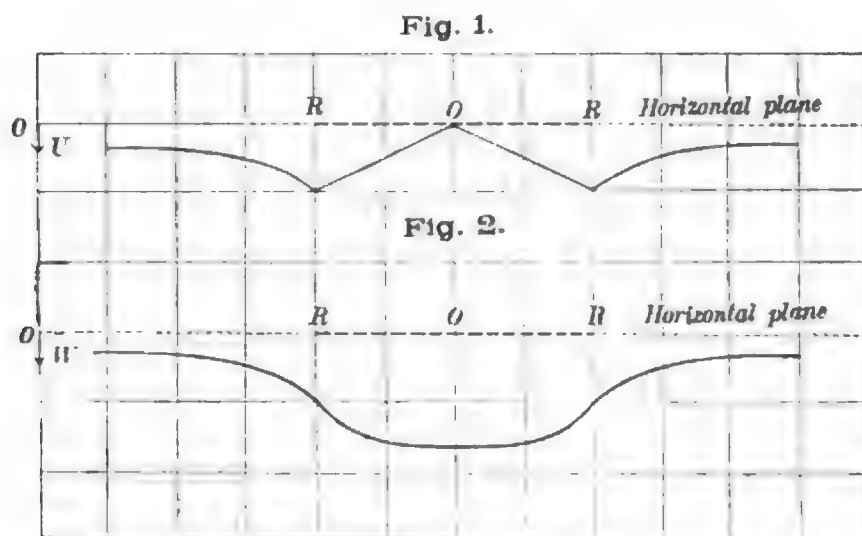
Evidently

$$w_0 = - \frac{2(\lambda+2\mu)}{\pi^2\mu(\lambda+\mu)} p_0 a \theta_3(o) \theta''_3(o) \quad \text{for } a \geq R$$

and

$$w_0 = -\frac{2(\lambda+2\mu)}{\pi^2\mu(\lambda+\mu)} p_0 R \frac{\partial''_2(o)}{\partial_2(o)\partial_3^2(o)} \quad \text{for } a \leq R.$$

both of which are easily expressed in terms of q .



§ 5. Pressure over a Circular Area given by

$$p = P_0 - \rho^{2n}$$

In the present case we have to calculate

$$(9) \quad \int_0^R \int_0^\pi \frac{(P_0 - \rho^{2n}) \rho d\rho d\phi}{\sqrt{a^2 - \rho^2 \sin^2 \phi}}$$

for finding the vertical displacement at an external point.

For the sake of brevity, let us put

$$J_n = \int_0^R \frac{\rho^{2n+1} d\rho}{\sqrt{a^2 - \rho^2 \sin^2 \phi}}$$

$$a^2 = a, \quad \sin^2 \phi = \beta, \quad \rho^2 = x;$$

then

$$J_n = \frac{1}{2} \int_0^{R^2} \frac{x^n dx}{\sqrt{a + \beta x}}$$

Putting $z^2 = a + \beta x$, we obtain

$$J_n = \int^{\Delta} \frac{(z^2 - a)^n}{\beta^{n+1}} dz \quad \text{where} \quad \Delta = \sqrt{1 - \frac{k^2}{a^2} \sin^2 \varphi}$$

which is easily integrable.

Let us consider two particular cases.

$n = 1$:—

$$J_1 = \frac{a^3}{\sin^4 \varphi} \left(\frac{\Delta^3}{3} - \Delta + \frac{2}{3} \right)$$

$n = 2$:—

$$J_2 = \frac{a^5}{\sin^6 \varphi} \left(\frac{\Delta^5}{5} - \frac{2\Delta^3}{3} + \Delta + \frac{8}{15} \right)$$

Putting $\int_0^{\varphi} \frac{d\varphi}{J} = u$, we have

$$\Delta = \operatorname{dn} u, \quad \sin \varphi = \operatorname{sn} u,$$

whence for

$$I_n = \int_0^{\pi/2} J_n d\varphi$$

we get

$$I_1 = a^3 \int_0^K \frac{1}{\operatorname{sn}^4 u} \left(\frac{\operatorname{dn}^4 u}{3} - \operatorname{dn}^2 u \right) du + \frac{2a^3}{3} \int_0^{\pi/2} \frac{d\varphi}{\sin^4 \varphi}$$

$$I_2 = a^5 \int_0^K \frac{1}{\operatorname{sn}^6 u} \left(\frac{\operatorname{dn}^6 u}{5} - \frac{2\operatorname{dn}^4 u}{3} + \operatorname{dn}^2 u \right) du + \frac{8a^5}{15} \int_0^{\pi/2} \frac{d\varphi}{\sin^6 \varphi}$$

The integrands can be easily reduced to the following forms.

$$\frac{1}{\operatorname{sn}^4 u} \left(\frac{\operatorname{dn}^4 u}{3} - \operatorname{dn}^2 u \right) = \frac{k^4}{3} + \frac{1}{3} - \frac{k^2}{\operatorname{sn}^2 u} - \frac{2}{3\operatorname{sn}^4 u}$$

$$\frac{1}{\operatorname{sn}^6 u} \left(\frac{\operatorname{dn}^6 u}{5} - \frac{2}{3} \operatorname{dn}^4 u + \operatorname{dn}^2 u \right) = k^2 - \frac{16}{15} \frac{k^4}{\operatorname{sn}^2 u} - \frac{4}{15} \frac{k^2}{\operatorname{sn}^4 u} + \frac{8}{15 \operatorname{sn}^6 u}$$

Using the formula of recursion

$$\begin{aligned} \int_0^{2n-3} \operatorname{sn} u \operatorname{cn} u \operatorname{dn} u = (2n-3) \int_0^{2n-4} u \operatorname{sn} u \operatorname{cn} u \operatorname{dn} u - (2n-2)(1+k^2) \int_0^{2n-2} u \operatorname{sn} u \operatorname{cn} u \operatorname{dn} u \\ + (2n-1)k^2 \int_0^{2n} u \operatorname{sn} u \operatorname{cn} u \operatorname{dn} u \end{aligned}$$

we easily find

$$\begin{aligned} \int \frac{du}{\operatorname{sn}^2 u} &= -\frac{\operatorname{cn} u \operatorname{dn} u}{\operatorname{sn} u} + k^2 \int \operatorname{sn}^2 u \operatorname{dn} u \\ \int \frac{du}{\operatorname{sn}^4 u} &= -\frac{\operatorname{cn} u \operatorname{dn} u}{3 \operatorname{sn}^3 u} + \frac{2}{3}(1+k^2) \left(k^2 \int \operatorname{sn}^2 u \operatorname{dn} u - \frac{\operatorname{cn} u \operatorname{dn} u}{\operatorname{sn} u} \right) - \frac{k'u}{3} \\ \int \frac{du}{\operatorname{sn}^6 u} &= -\frac{\operatorname{cn} u \operatorname{dn} u}{5 \operatorname{sn}^5 u} + \frac{4}{3}(1+k^2) \int \frac{du}{\operatorname{sn}^4 u} - \frac{3}{5} k' \int \frac{du}{\operatorname{sn}^2 u} \end{aligned}$$

Remembering that at the limits

$$\begin{array}{ll} u=0 & \text{and} \quad u=K \\ \operatorname{dn}(0)=1 & \operatorname{dn}(K)=k' \\ \operatorname{sn}(0)=0 & \operatorname{sn}(K)=1 \\ \operatorname{cn}(0)=1 & \operatorname{cn}(K)=0 \\ Z(0)=0 & Z(K)=0 \end{array}$$

we get

$$\int_0^K \left(\frac{k^4}{3} + \frac{k^2}{3 \operatorname{sn}^4 u} - \frac{2}{3 \operatorname{sn}^2 u} \right) du + \frac{2}{3} \int_0^{\frac{\pi}{2}} \frac{d\varphi}{\sin^4 \varphi} = \frac{4(k^2-1)}{9} K + \frac{4+k^2}{9} E$$

After all the necessary reductions, we find that at points external to the circle, the vertical displacement of the horizontal plane amounts to

$$(10) \quad w_0 = \frac{2(\lambda+2\mu)}{9\pi\mu(\lambda+\mu)} \frac{p_0 a^3}{R^2} \left\{ 2(1-2k'^2)E - k'^2(1-3k'^2)K \right\}$$

when the pressure distribution is given by

$$p = p_0(R^2 - \rho^2)$$

In the interior of the circle, we have to calculate

$$\frac{2\pi\mu(\lambda+\mu)}{(\lambda+2\mu)p_0} w_0'' = \int_0^R \int_0^{\frac{\pi}{2}} \frac{(R^2 - \rho^2)\rho d\rho d\varphi}{\sqrt{\rho^2 - a^2 \sin^2 \varphi}}$$

$$\begin{aligned}
&= \frac{2R^3}{3} \int_0^{\kappa} dn' w l u - R a + \frac{R^2 a k^2}{3} + \frac{2a^3}{9} \\
&= \frac{2R^3 \{2(1+k'^2)E - k'^2 K\}}{9} - R a^2 + \frac{5a^3}{9} \\
&\quad \text{where } k^2 = \frac{a^2}{R^2}, \quad k'^2 = \frac{R^2 - a^2}{R^2}
\end{aligned}$$

Add to this

$$\int_0^a \int_0^{2\pi} \frac{(R^2 - \rho^2) \rho d\rho d\varphi}{\sqrt{a^2 - \rho^2} \sin^2 \varphi} = R a^2 - \frac{5a^3}{9}.$$

Consequently,

$$\begin{aligned}
(10_a) \quad w_0 &= \frac{(\lambda + 2\mu)p}{9\pi\mu(\lambda + \mu)} R \{2(1 + k'^2)E - k'^2 K\} \quad \text{where } k = \frac{a}{R} \\
&\quad \text{and } R \geq a.
\end{aligned}$$

Thus at the centre of the circle, the depression amounts to

$$w_0 = \frac{\lambda + 2\mu}{6\mu(\lambda + \mu)} R$$

and at the boundary

$$w_0 = \frac{2(\lambda + 2\mu)}{9\pi\mu(\lambda + \mu)} R$$

As regards the horizontal displacement, we have for the law

$$p = p_0(R^2 - \rho^2)$$

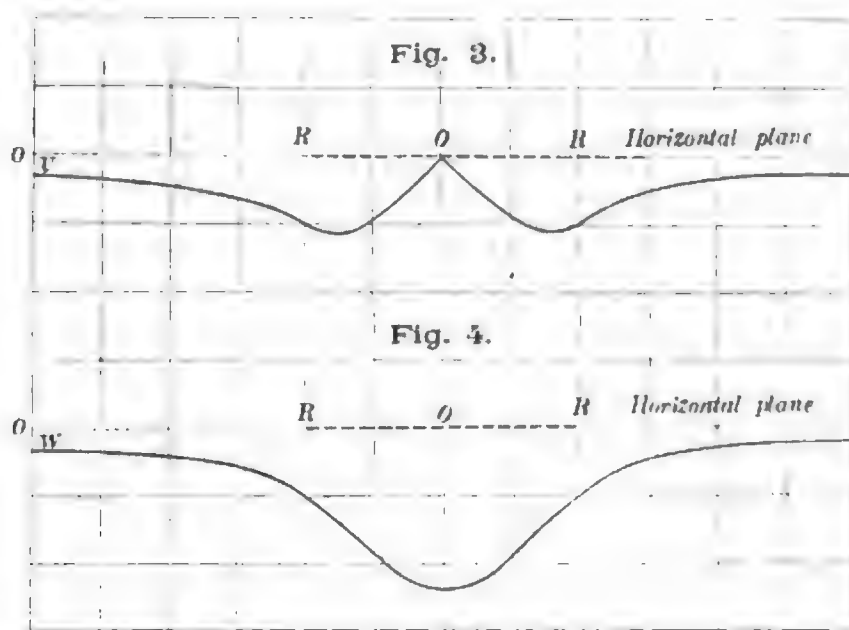
$$(11) \quad U = -\frac{p_0 R^2}{8(\lambda + \mu)a} \quad \text{for an external point}$$

and

$$(11_a) \quad U = -\frac{p_0 a(2R^2 - a^2)}{8(\lambda + \mu)R^2} \quad \text{" " internal point.}$$

The formulas (11) (11_a) show that the horizontal displacement for the pressure distribution $p = p_0(R^2 - \rho^2)$ is somewhat similar to that already found for uniform pressure. The difference arises in the neighbourhood of the periphery $\rho = R$, where the maximum displacement is to be found. Fig. 3 gives the diagram of the horizontal displacement. As to the vertical displacement, and the complicated

functions by which it is expressed is rather difficult to judge, but constructing a diagram (Fig. 4), we easily find that the depression is quite large at the centre, and the tilting is generally more uniform than for constant distribution of pressure. At distant points, the asymptotic approach to the horizontal plane is evident from the figures.



§ 6. Finally, let us find the depression in the vertical line through the centre. Evidently the sinking in depth z is given by

$$w_z = \frac{\lambda + 2\mu}{4\pi\mu(\lambda + \mu)} \int \frac{dP}{r} + \frac{z^2}{4\pi\mu} \int \frac{dP}{r^3}$$

where $r^2 = \rho^2 + z^2$, x and y being put equal to zero. For uniform pressure p_0 ,

$$w_z = \frac{p_0(\lambda + 2\mu)}{4\pi\mu(\lambda + \mu)} \int_0^R \int_0^{2\pi} \frac{\rho d\rho d\theta}{\sqrt{z^2 + \rho^2}} + \frac{p_0 z^2}{4\pi\mu} \int_0^R \int_0^{2\pi} \frac{\rho d\rho d\theta}{(z^2 + \rho^2)^{3/2}}$$

Putting $\frac{R}{z} = \tan a$, we get

$$(12) \quad w_z = \frac{p_0 R}{2\mu} \tan a \left(2 \sin^2 \frac{a}{2} + \frac{\mu}{\lambda + \mu} \right)$$

when the pressure distribution is given by $p = p_0(R^2 - \rho^2)$

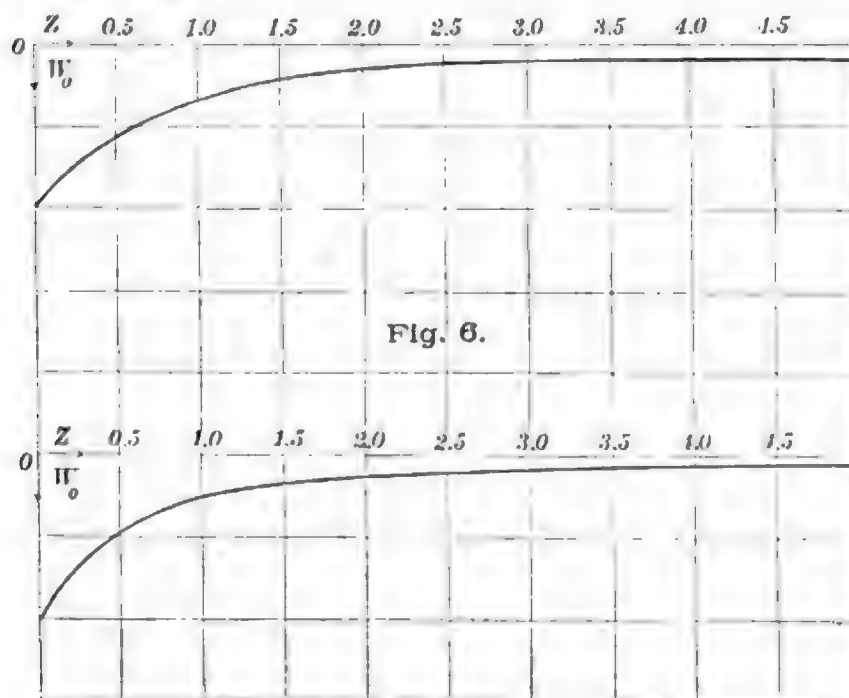
$$w_z = \frac{(\lambda + 2\mu)p_0}{4\pi\mu(\lambda + \mu)} \int_0^R \int_0^{2\pi} \frac{(R^2 - \rho^2)\rho \, d\rho \, d\theta}{R^2 \sqrt{z^2 + \rho^2}} + \frac{z^2}{4\pi\mu} \int_0^R \int_0^{2\pi} \frac{(R^2 - \rho^2)\rho \, d\rho \, d\theta}{R^2(z^2 + \rho^2)^{\frac{3}{2}}}$$

which by easy integration becomes

$$(13) \quad w_z = -\frac{p_0 R}{4\eta} \frac{\sin \frac{\alpha}{2}}{\cos^3 \frac{\alpha}{2}} \left\{ \cos 2\alpha + \frac{(\lambda + 2\mu)(1 - 3 \cos^2 \frac{\alpha}{2})}{3(\lambda + \mu)} \right\}.$$

These two formulas (12) and (13) show that the vertical depression in the central line of the stressed circle diminishes gradually, so that we may expect the effect to be felt at a considerable depth, provided the radius of the region of pressure is large. In the application to technical problems, R may be a small quantity, but in geophysical questions as regards the region of low pressure or of heavy rainfall, the result above arrived at will be of special interest. Fig's 5 and 6 show how the depression diminishes with the depth.

$R =$ Fig. 5.



§ 7. For the distributions of stress above considered, I have constructed the contour lines of equal depressions as shown in Fig.'s 7 and 8 Pl. I. From these diagrams, it is evident that the gradient of depression is greater near the periphery of the area of pressure. It is less marked for the case in which the pressure reaches a maximum value at the centre than for a uniform distribution.

When the depression due to pressures over two circular areas is to be found, we have to apply the principle of the superposition of small displacements. The effect can be most easily effected by using the same method of procedure as finding the equipotential lines by adding systems of such lines due to distinct sources. The depressions due to two positive or negative pressures over circular areas are represented in Fig. 9 and 10 *a, b, c*, Pl. II. These diagrams resemble the equipotential lines due to two attracting or repelling sources. When negative pressure is exerted over one portion and positive pressure over the other, the lines of equal depression take the form given in Fig. 11 *a, b*, Pl. III.

§ 8. For those interested in seismology, it would not be out of place to state one or two instances of the amount of depression due to surface loading. Supposing the elastic medium to consist of andesite, we have to use the following elastic constants.*

$$\mu = 6 \times 10^{10} \text{ (C. G. S.)}$$

$$\frac{\mu(3\lambda + 2\mu)}{\lambda + \mu} = \text{Young's modulus} = 8.80 \times 10^{10} \text{ (C. G. S.)}$$

When the pressure is uniform and $p_0 = 1$ cm. weight of mercury per cm^2 , and $R = 50$ km., the depression at the periphery

$$w = 1.15 \text{ cm.}$$

and at the centre

$$w_0 = 1.80 \text{ cm.}$$

so that the mean tilting amounts to about $0''.02$.

For $p = p_0(R^2 - r^2)$, and $p_0 R^2 = 1$ cm. weight of mercury

* H. Nagaoka, Pub. Earthq. Inv. Comm., No. 4, p. 60.

$w_0 = 0.52$ cm. at the periphery

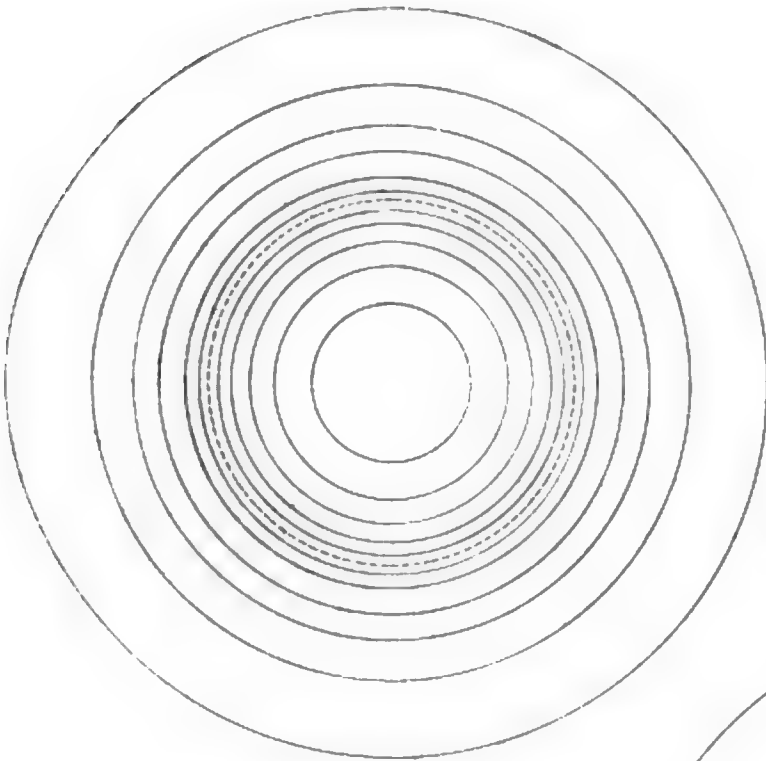
$w_0 = 1.23$ cm. „ „ centre

and the mean tilting is about 0."02 as before. The elastic constants of the surface soil are evidently several times weaker than the andesite, so that the barometric change or rainfall might produce effects which would be within the limit of observation. With elastic solid of high plasticity, and with continuous application of pressure, there will be gradual increase of the strain, so that the effect may sometimes accumulate and at last attain an appreciable amount.

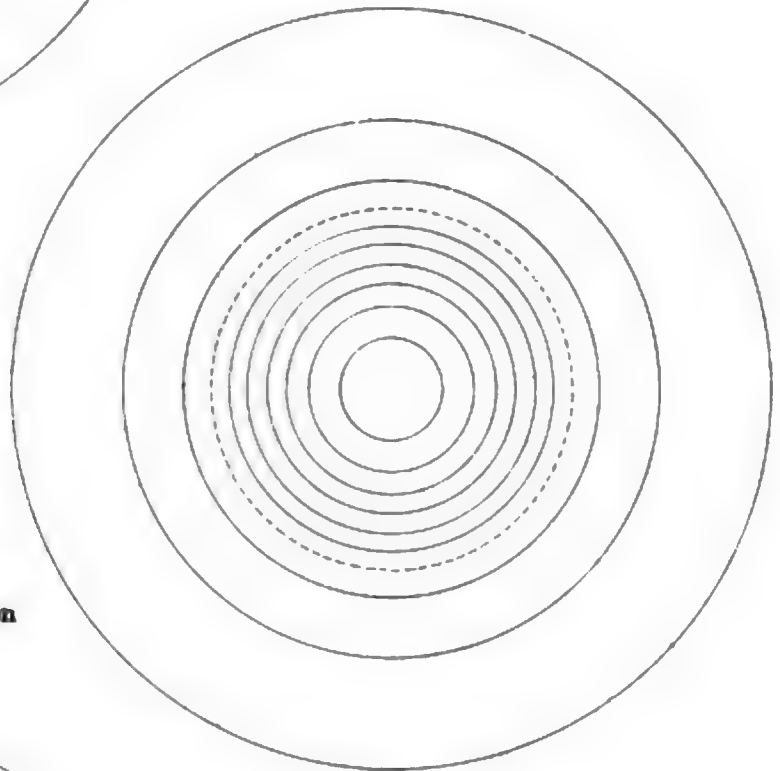
What will interest the seismologist in the present problem is the extent to which the strain due to vertical pressure is appreciable. If the area of pressure be confined to a small portion of the surface, the horizontal and the vertical components will practically vanish in its immediate neighbourhood, but the strained area increases almost in the same proportion as the stressed region, so that in the actual problem of the barometric change or of heavy rainfall, the effect would also be felt in places apparently remote from the place subjected to differences of surface pressure. The evanescence of the strain takes place almost asymptotically as already shown in the diagram, so that it will slightly disturb the elastic equilibrium and call forth vibrations or tremors. The surface wave which is most likely to be excited on the horizontal boundary and which is easily accessible to observation forms the next subject of discussion. Another problem, which will be interesting for seismology and volcanology is the strain on the horizontal surface, produced by internal pressure, a subject which I hope to be able to discuss in the near future.

Art. 1, Nagaoka, Pl. I.

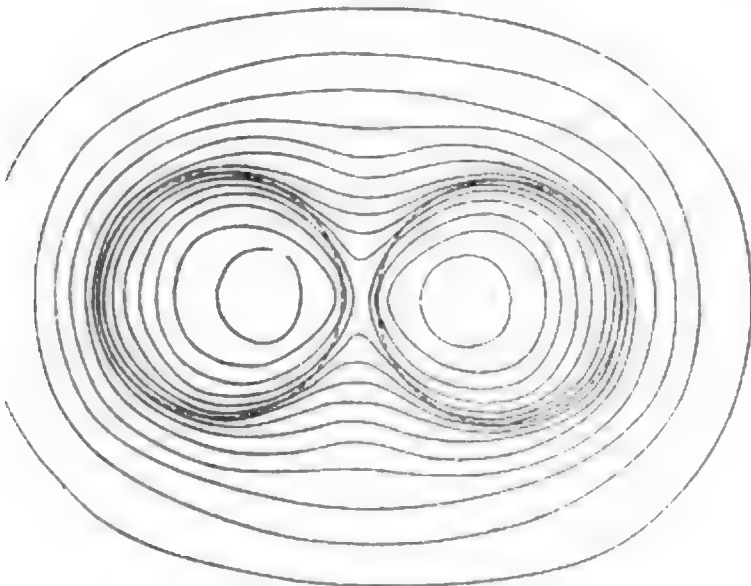
Depression due to $p=p_0$. (Fig. 7.)



Depression due to $p=p_0(R^2-r^2)$ (Fig. 8.)

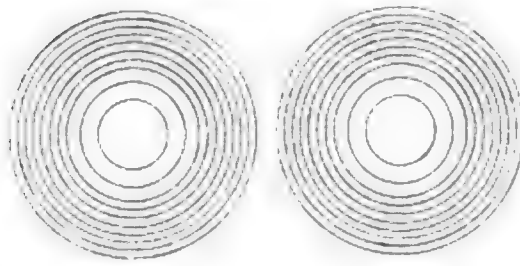


Depression due to symmetrical distribution
of pressure $p=p_0$. (Fig. 9.)

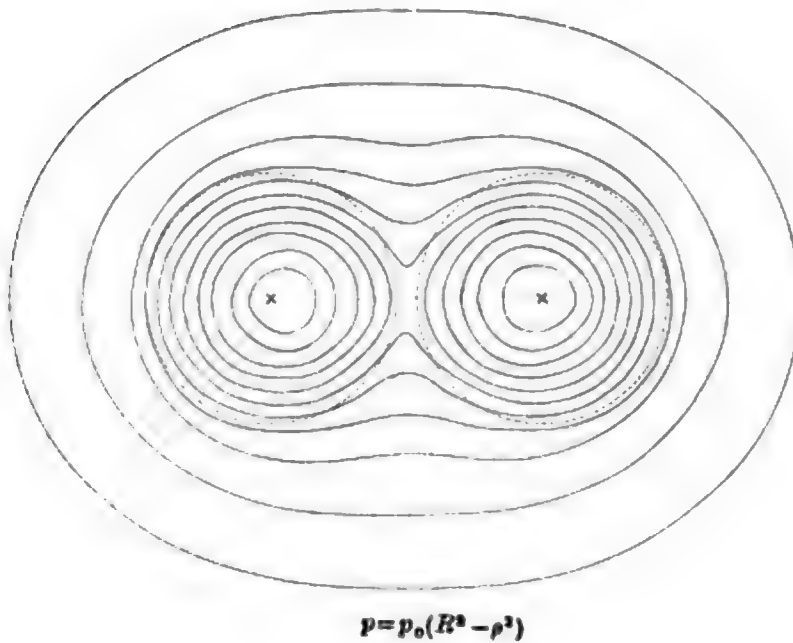


Art. 1, Nagaoka, Pl. II.

Pressure distribution. (Fig. 10a)



Depression due to symmetrical distribution of
pressure = $p_0(R^2 - \rho^2)$ (Fig. 10b)

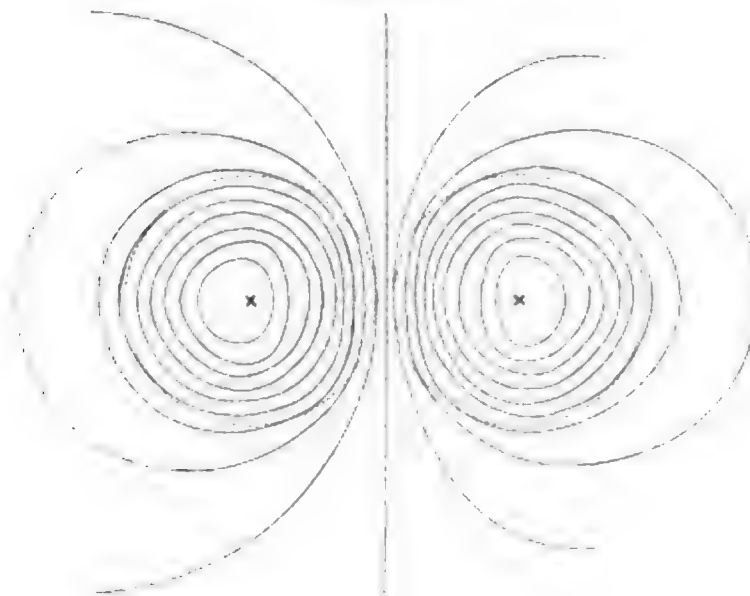


$$p = p_0(R^2 - \rho^2)$$

Elevation due to
 $p = -p_0(R^2 - \rho^2)$

Depression due to
 $p = p_0(R^2 - \rho^2)$

(Fig. 10c)

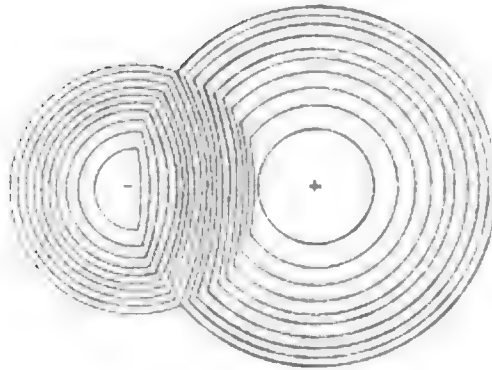


$$p = -p_0(R^2 - \rho^2)$$

$$p = p_0(R^2 - \rho^2)$$

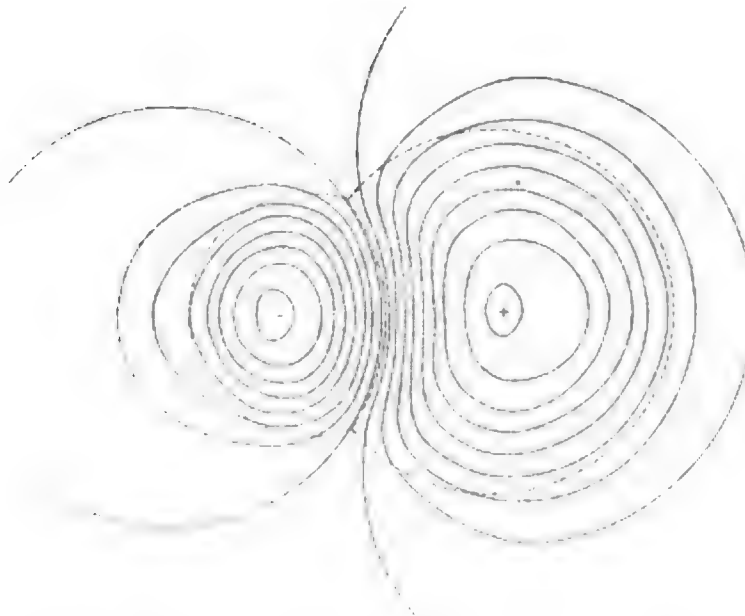
Art. 1, Nagaoka, Pl. III.

(Fig. 11a)



Distribution of pressure

(Fig. 11b)



Depression due to unsymmetrical distribution of pressure.

Stationary Surface Tremors

By

H. NAGAOKA, *Riyakuhakushi*.

Member of the Earthquake Investigation Committee

With Plates I.

§ 1. The problem of elastic surface waves on an isotropic solid was first treated by Lord Rayleigh* in a paper communicated to the London Mathematical Society in 1885. The important bearing of this class of waves on earthquakes was recognised by him, but the result of analysis in its practical aspect has scarcely been discussed, inasmuch as the hypothesis of isotropy of the medium is hardly compatible with the structure of the earth's crust. When the great complexity which will be introduced into the boundary conditions if the stratigraphical structure such as is actually met with is taken into account, the advantage gained does not easily compensate for the mathematical difficulty which necessarily accrues in the solution of the problem. But if the result of calculation based on a simple abstraction as to the nature of the medium be interpreted in the light of a simple comment as to the character of the motion which is capable of being excited on the surface of the elastic solid, the analysis would not be a useless piece of mathematical play, as the conception of the phenomena is thereby greatly facilitated. A mere quantitative discrepancy will not prove imperfection of the theory, but one notices at a glance that the hypothesis made at the outset of calculation necessarily deviates from what is found in nature, where the intricacy and heterogeneity far surpass the power of modern analysis. The greatest objec-

* Lord Rayleigh, Proc. London Mathem. Soc., Vol. 17, 4. 1877

tion which can perhaps be raised against the present treatment of the problem is the neglect of the influence of gravity in modifying the surface wave.

§ 2. Take the xy -plane at the horizontal boundary, and z -axis vertically downwards, and denote the component displacements by u , v , w ; then the equations of motion becomes.

$$(1) \quad \rho \frac{\partial^2 u}{\partial t^2} = (\lambda + \mu) \frac{\partial \theta}{\partial x} + \mu \Delta u$$

with similar equations for v and w . Here ρ denotes the density, λ , μ Lamé's constants, and

$$\theta = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

$$\Delta \theta = \frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2}$$

For the free vibration of period $\frac{2\pi}{p}$, the equations can be easily reduced to the form

$$(2) \quad \begin{cases} (\lambda + k^2) u = \left(1 - \frac{k^2}{h^2}\right) \frac{\partial \theta}{\partial x} \\ (\lambda + k^2) v = \left(1 - \frac{k^2}{h^2}\right) \frac{\partial \theta}{\partial y} \\ (\lambda + k^2) w = \left(1 - \frac{k^2}{h^2}\right) \frac{\partial \theta}{\partial z} \end{cases}$$

where

$$(3) \quad \begin{cases} h^2 = \frac{\rho}{\lambda + \mu} p^2 \\ k^2 = \frac{\rho}{\mu} p^2 \end{cases}$$

The equations can therefore be satisfied by

$$(4) \quad \begin{cases} u = -\frac{1}{h^2} \frac{\partial \theta}{\partial x} \\ v = -\frac{1}{h^2} \frac{\partial \theta}{\partial y} \\ w = -\frac{1}{h^2} \frac{\partial \theta}{\partial z} \end{cases}$$

to which we shall have to add the complementary solutions satisfying

$$(5) \quad (\mathcal{A} + k^2)u = 0, \quad (\mathcal{A} + k^2)v = 0, \quad (\mathcal{A} + k^2)w = 0.$$

with the condition

$$\theta = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0.$$

For the surface wave on the plane $z=0$, the displacements are proportional to

$$e^{i(fx+gy+iz)},$$

where f, g are constants to be determined by the boundary conditions.

By differentiating (4) with respect to x, y, z , we find

$$(6) \quad (\mathcal{A} + k^2)\theta = 0.$$

or

$$(6') \quad \frac{\partial^2 \theta}{\partial z^2} - (f^2 + g^2 - k^2)\theta = 0.$$

Thus $\theta = Pe^{-rz}$ where $r^2 = f^2 + g^2 - k^2$

The equation (5) can be written

$$(7) \quad \frac{\partial^2 u}{\partial z^2} - (f^2 + g^2 - k^2)u = 0.$$

or $u = Ae^{-sz}$ where $s^2 = f^2 + g^2 - k^2$

Thus (4) and (5) give for u, v, w

$$(8) \quad \begin{cases} u = -\frac{if}{k^2} Pe^{-rz} + Ae^{-sz} \\ v = -\frac{ig}{k^2} Pe^{-rz} + Be^{-sz} \\ w = -\frac{r}{k^2} Pe^{-rz} + Ce^{-sz} \end{cases}$$

where P, A, B, C are all proportional to $e^{i(fx+gy+iz)}$ and A, B, C are connected by the relation

$$(8') \quad i(fA + gB) - sC = 0$$

which is equivalent to $\theta=0$, in the complementary term.

The absence of shear at the horizontal boundary $z=0$ leads to the relation

$$(9) \quad (s^2 + f^2 + g^2)h^2C + 2r(f^2 + g^2)P = 0,$$

while the evanescence of the normal surface traction is expressed by

$$(10) \quad (k^2 - 2h^2)P - 2(r^2 + sh^2C) = 0.$$

Eliminating C and P between (9) and (10), we obtain

$$(11) \quad \{2(f^2 + g^2) - k^2\} = 16(f^2 + g^2)^2(f^2 + g^2 - h^2)(f^2 + g^2 - k^2)$$

Remembering that

$$\frac{h^2}{k^2} = \frac{\mu}{\lambda + 2\mu},$$

and putting

$$\gamma^2 = \frac{k^2}{f^2 + g^2} = \frac{\rho}{\mu(f^2 + g^2)}p^2$$

we arrive at the equation

$$(12) \quad \gamma^6 - 8\gamma^4 + 24\gamma^2 - 16 - 16\left(\frac{\mu}{\lambda + 2\mu}\right)(\gamma^2 - 1) = 0.$$

for finding the frequency p of the free vibration, as given by Rayleigh.

The following real roots of γ have been calculated for different values of $\frac{\mu}{\lambda + 2\mu}$ (with corresponding ratio σ of lateral contraction to longitudinal elongation).

$\frac{h^2}{k^2} = \frac{\mu}{\lambda + 2\mu}$	σ	$\gamma = \frac{k}{\sqrt{f^2 + g^2}}$
.0	$\frac{1}{2}$	0.9554
.1	$\frac{4}{9}$	0.9482
.2	$\frac{3}{8}$	0.9387
.3	$\frac{2}{7}$	0.9251

.4	$\frac{1}{6}$	0.9052
.5	0	0.8741
.6	$-\frac{1}{4}$	0.8237

r being determined for a given boundary, the displacements u , v , w are given by

$$(13) \quad \begin{cases} u = a \frac{if}{h^2} \left\{ e^{-rz} + \frac{2rs}{s^2 + f^2 + g^2} e^{-sz} \right\} e^{i(\mu t + fx + gz)} \\ v = a \frac{ig}{h^2} \left\{ e^{-rz} + \frac{2rs}{s^2 + f^2 + g^2} e^{-sz} \right\} e^{i(\mu t + fx + gz)} \\ w = a \frac{r}{h^2} \left\{ e^{-rz} - \frac{2(f^2 + g^2)}{s^2 + f^2 + g^2} e^{-sz} \right\} e^{i(\mu t + fx + gz)} \end{cases}$$

a being a constant to be found from the initial condition.

When there are several values of u_n , v_n , w_n for u , v , w corresponding to different values of f and g , and consequently p , the displacements will be given by

$$(14) \quad u = \Sigma u_n, \quad v = \Sigma v_n, \quad w = \Sigma w_n.$$

§ 3. When the elastic solid is bounded by two parallel planes, the discussion of waves can be generally reduced to that in two dimensions. If the bounding planes be given by

$$x=0, \quad x=a, \quad \text{and} \quad z=0,$$

the surface wave would be generally given by the components u and w only.

Three different cases are to be distinguished.

(I) When both planes $x=0$, $x=a$ are clamped; then u varies as $\sin fx$ and

$$f = \frac{n\pi}{a},$$

consequently

$$(15) \quad \nu_n = r \frac{n\pi}{a} \sqrt{\frac{\mu}{\rho}} \quad (n = 1, 2, 3, \dots)$$

and the complete period is given by

$$(15') \quad T_n = \frac{2\pi}{\nu_n} = \frac{2a}{n r \sqrt{\frac{\mu}{\rho}}}$$

Writing $a \frac{f}{h} \left(-e^{-rs} + \frac{2rs}{s^2 + f^2} e^{-rs} \right) = A_n$

$$a \frac{r}{h^2} \left(e^{-rs} - \frac{2f^2}{s^2 + f^2} e^{-rs} \right) = C_n$$

where r, s are expressed by the above value of f ,

$$(16) \quad \begin{cases} u_n = A_n \frac{\cos p_n t}{\sin p_n t} \sin n\pi \frac{x}{a} \\ w_n = C_n \frac{\sin p_n t}{\cos p_n t} \sin n\pi \frac{x}{a} \end{cases}$$

satisfy the specified condition, so that the sum of these expressions will also represent the possible forms of surface waves.

II. When one boundary is clamped and the other is free,

$$u = 0 \quad \text{for} \quad x = 0$$

and $\frac{\partial u}{\partial x} = 0 \quad ,, \quad x = a.$

Thus

$$u \propto \sin fx$$

where

$$(17) \quad f = \frac{2n+1}{2} \frac{\pi}{a} \quad (n = 0, 1, 2, 3, \dots)$$

and $p_n = \frac{2n+1}{2} \frac{\pi}{a} r \sqrt{\frac{\mu}{\rho}}$

or

$$T_n = \frac{4}{2n+1} \frac{a}{r \sqrt{\frac{\mu}{\rho}}}$$

The displacements are given by

$$(18) \quad \begin{cases} u_n = A_n' \cos p_n t \sin \left(\frac{2n+1}{2} \right) \frac{\pi x}{a} \\ w_n = C_n' \sin p_n t \sin \left(\frac{2n+1}{2} \right) \frac{\pi x}{a} \end{cases}$$

III. When both planes $x=0$, $x=a$ are free,

$$\frac{\partial u}{\partial x} = 0 \quad \text{for} \quad \begin{matrix} x=0 \\ x=a \end{matrix}$$

and $u \propto \cos fx$.

Evidently

$$(19) \quad f = \frac{n\pi}{a} \quad (n=1, 2, 3, \dots)$$

and $p_n = \frac{n\pi}{a} \gamma \sqrt{\frac{\mu}{\rho}}$

or
$$T_n = \frac{2a}{n\gamma \sqrt{\frac{\mu}{\rho}}}$$

which is the same as for clamped boundaries.

Consequently

$$(20) \quad \begin{cases} u_n = A_n \sin p_n t \cos \frac{n\pi}{a} x, \\ w_n = C_n \cos p_n t \cos \frac{n\pi}{a} x. \end{cases}$$

§ 4. The case which is really worth consideration is when the boundary is yielding to a certain amount. As the surface soil is characterised by its plasticity, and the unevenness of the bounding surface makes the approach to the ideal case somewhat difficult, the general discussion of the yielding boundary in its application to geophysics may with propriety be postponed till the main cause of the surface tremors is well settled by observation. If we allow for the deviations in the actual case from what is assumed in the above discussion, the first case would correspond to the vibrations of a plain

between parallel mountain ranges, the second case to those of a plain isolated by a ridge on one side and a mountain range on the other, and the third case to those of a high plateau or of a plain between two parallel rivers.

To give a numerical instance, let us suppose that $a=10$ km.
 $\sqrt{\frac{\mu}{\rho}} = 3 \frac{\text{km}}{\text{sec}}$, $\gamma=0.9$, then

$$\begin{aligned} & \left\{ \begin{array}{l} T_1 = 7.4 \\ T_2 = 3.7 \end{array} \right. \quad \text{for (I) and (III)} \\ \text{and} \quad & \left\{ \begin{array}{l} T_0 = 14.8 \\ T_1 = 4.9 \end{array} \right. \quad \text{,, (II).} \end{aligned}$$

The above result shows that the vibration is quite analogous to the longitudinal vibration of rods; the nodes and loops are to be found in places which are aliquot parts of the breadth. The velocity of propagation is not so simply defined as in the case of rods.

The velocity of transversal wave $\sqrt{\frac{\mu}{\rho}}$ is perhaps very small for the uppermost strata of the earth's crust and probably much less than $3 \frac{\text{km}}{\text{sec}}$. When the plain on which the surface wave is excited is of considerable extent, the period of stationary wave may attain a tolerably large value. If such motion be stimulated by progressive seismic waves, there is every possibility of the motion being traced on seismographs. One great drawback in seismometers is the impossibility of the discrimination of the progressive from the stationary waves. I am not aware if such waves have ever been observed, but it would not be out of place here to notice the probable appearance of vibrations of long periods.

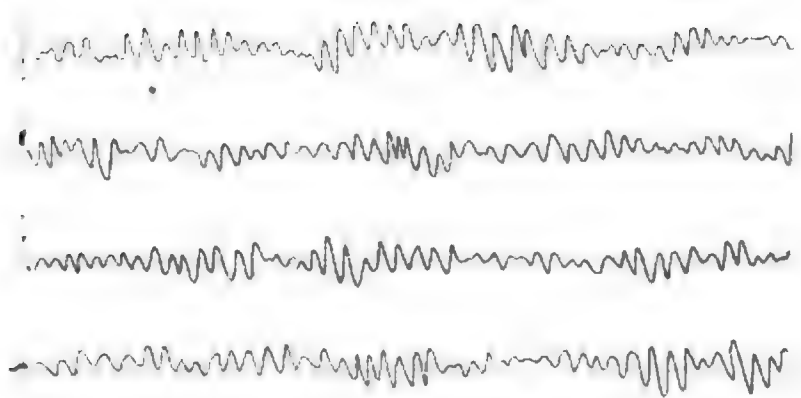
The tremors accompanying the barometric change generally indicate persistence of surface waves for some intervals of time. As the surface soil is strongly damped, the evanescence will be quick; but the surface pressure is generally accompanied with strains, as already shown in the preceding paper, in regions quite remote from the place of actual application. The extent to which the horizontal component of the surface strain is felt is

linearly related to the radius of the circular region subjected to stress. As is often met with on the earth's surface, the region of low pressure or of strong rainfall is not limited to a narrow space, but extends over hundreds or sometimes thousands of kilometres; the consequence is that the region in which the surface wave is liable to be excited is of vast extent. In countries which abound with mountains, interspersed with plains between, the surface waves may be either propagating or stationary, so long as the disturbing force is acting, whether the point under consideration be within the pressure domain or outside it.

The inspection of the diagram of tremors at once indicate the existence of beats in the vibrations. These are of exactly the same nature as is observed in the sea waves on calm days, where the bottom is irregular. These beats are probably due to the superposition of two vibrations of nearly equal periods and amplitudes. In the case of earth tremors, the existence of two such vibrations is to be traced to the nonuniformity of the surface strata, when either the elastic constants or the thickness of the horizontal strata are slightly different, there will be superposition of two waves giving rise to beats analogous to those well known in light and sound.

§ 6. The fulfilment of the boundary condition in the present problem offers insurmountable difficulty to exact calculation, except for those boundaries which are conformable to rectangular coordinates or circles. The result of calculation in its practical application is only a rough approximation, and probably represents a part of the phenomena of earth tremors in its broadest aspect. The discussion of the present problem with special analogies to sea waves will not fail to be of special interest to those pursuing the study of geophysics, as there are so many points of resemblance between the two. I have therefore thought it advisable to give a diagram of sea waves observed at Odawara on a calm day, to show the close kinematical analogies which may exist between these two phenomena.

Tremor.



Sea wave.





A Kinetic Measurement of the Modulus of Elasticity

FOR

158 SPECIMENS OF ROCKS:

AND

A NOTE ON THE RELATION BETWEEN THE KINETIC AND STATIC MODULI.

BY

S. KUSAKABE, *Rigakushi.*

With Plates I-II.

Introduction.

The importance of measuring the elastic constants of rocks by a kinetic method may be easily recognized, from the great deviation of the Newtonian velocity, in the case of sound waves, from the actual one. In No. 17 of "the Publications," the author reported some experimental researches relating to static modulus of elasticity of rocks. A little consideration, however, will show that the value of elastic constants determined by a statical method is but a rough approximation to be used in the discussion of wave velocity. Not only are the rapid alteration of state concerned in the propagation of wave attended with thermal effect, but also, in the case of rocks, the phenomenon of yielding may have great influence to make them further deviate from the actual state.

Possibly sound-experiments is the best method of ascertaining the kinetic modulus of elasticity. The result deduced from such infinitely small strains as in sound vibration is no doubt of great value as regards the elastic property of rocks, and may have a close relation to the propagation of seismic waves. As it may seem strange to speak

of vibration of such loose rocks as sandstone, the measurement of the kinetic modulus of elasticity is not so easy as in the metallic substances.

The method to be described here is an application of Melde's experiment, combined with the principle of resonance. The number of rocks examined amounts to one hundred fifty eight different specimens collected from various localities in the main land of Japan. There are 23 archæan rocks, 65 palæozoic rocks, 12 mesozoic rocks and 58 cainozoic rocks. The whole experiment is, indeed, but a beginning in this field of inquiry, and may be strewn as a wreck in course of further progress. Still I hope that it will form a stepping-stone to later investigations.

Method of measurement.

The essence of Melde's experiment is that, on one hand, a massive fork excited by a bow or maintained in stationary state by electro-magnet, vibrates in a manner, which is approximately independent of the reactions of any light body, which may be connected with it, while on the other hand, the period of the forced vibration of the light body is determined solely by the period of the force which is supposed to act on the system from without.

The principle of resonance is merely that the kinetic energy or the amplitude of any forced vibration is the greatest possible, when the period of the external force is that in which the system would vibrate freely under the influence of its own elasticity. The number of free vibrations of a string of given length may be easily calculated when we know its linear density and the amount of tension.

The present method is simply as follows :

- a. A specimen of rock, whose one end is tightly clamped by a massive vice, is maintained in free vibration.
- b. A fine wire of known linear density w is connected with the free end of the specimen and stretched with a known tension.
- c. The length l of the above wire, in which the wire vibrates with maximum amplitude is measured.

The number of free vibrations of gravest mode for a perfectly flexible string is given by

$$n_1 = \frac{1}{2l} \sqrt{\frac{W \cdot g}{w}}$$

where W is the suspended weight to which the tension is due. But if we consider the string as not being infinitely thin, so that the radius of gyration k of the area of its section about an axis through its centre of inertia perpendicular to the plane of bending can not be neglected, which is actually the case for a metallic wire, its stiffness must be taken into account. In the case where the extremity of the wire is constrained to be a node by stretching it over a bridge but there acts no couple to fix its direction, the correction for a circular wire with radius r is given by

$$n_2 = \frac{\pi w^3 E'}{16 l^3 \rho'^2 \sqrt{W \cdot g}}$$

where ρ' and E' are the specific density and the modulus of elasticity of the wire respectively.

Thus, the number of vibration n of the specimen, which is identical with that of the connected wire, is given by

$$n = n_1 + n_2 = n_1 + \frac{\pi w E'}{32 \rho'^2} \frac{1}{n_1 l^3}$$

Another term of correction due to the effect of the wire connected at the free end may be easily known, since the effect of the small load MM is the same as a lengthening of the specimen, whose weight is M , in the ratio

$$M : M + MM.$$

On the other hand, the relation between Young's modulus E and the number of vibration of the specimen is given by

$$n = \frac{k}{2\pi L^2} m^2 \sqrt{\frac{E}{\rho}}$$

where k is the radius of gyration and ρ is the specific density of the specimen whose length is L ; while m is a constant satisfying the equation

$$\cos m \cosh m + 1 = 0.$$

The smallest root, 1.875, of course, corresponds to the gravest mode of vibration, while the second root, 4.694, and other successive roots correspond to the higher notes. The frequencies of the series of tones being proportional to m^2 , the first over-tone is $2\{\log 4.694 - \log 1.875\} \div \log 2 \doteq 2.6$ octaves higher than the gravest tone, so that in the actual case the gravest tone is the only one which can be easily measured.

So far as the method is concerned, the above statements are sufficient and nothing more is required. In laboratory work, however, there are several experimental difficulties to be overcome; especially, the maintenance of vibration and the fulfilment of the condition of a clamped end. The last condition is realised by means of a steel vice of massive construction, weighing ca. thirty kilograms. The vibration is maintained by a periodic impulse.

The distinction of forced from free vibrations is very important, and must be clearly stated. If a vibration is the response of the system to a force imposed upon it from without and is maintained by the continued operation of that force, it is obviously a forced vibration. But it must be remembered that any free vibration which we shall have in laboratory experiment takes its origin necessarily from a force acting upon it from without. At first, there is a forced vibration not less important than its rival, but when the force is removed, though there is no discontinuity in velocity or displacement, but the period of the force is at once exchanged for that natural to the system, and the forced vibration is converted into a free vibration.

In the present case, the specimen whose one end is clamped by the massive vice is tapped periodically by a hammer under electromagnetic maintenance. The frequency of the hammer, which is easily adjustable within wide limits by varying its moment of inertia, is about ten per second; while that of the specimen, as the case may be according to the age of the rock, lies between some three hundred and a thousand per second. Thus, between two consecutive tapings, the number of vibrations of the specimen amounts to some

thirty or hundred, so that the mode of vibration is necessarily of free nature.

Fig. 1. pl. II is the photograph of the whole arrangement, which is laid on a massive stone projecting from the floor of paved stones. A specimen clamped in the vice is tapped by a hammer, which is supported by a stand and maintained in stationary vibration by an electro-magnet. A fine copper wire, whose radius is about one-twentieth mm., is connected by means of bees wax at the upper end of the specimen and stretched over a bridge by a tension due to a suspended weight. The bridge may slide along an iron bench of length ca. 118 cm. in which a scale is graduated in mm. A microscope is also mounted on the bench to measure the amplitude of the vibrating string. The copper wire, whose breaking tension is ca. 140 grams, was first pulled by a tension of 100 grams for about 30 min. and then used as a vibrating string. During experiments, the tension of about ten or forty grams is sufficient.

Here it is necessary to remark that, although the vibration of the string is due the periodic force imparted from the specimen, the point of application of the force never corresponds to a loop, but, on the contrary, there is a node in that vicinity. Assuming the impressed force given by the vibrating rock, which is connected with the string at a point whose distance from the bridge is $x=b$, to vary as $F \cos pt$, the amplitude of the motion between the bridge and the rock is approximately given by

$$\gamma \left\{ \frac{\sin^2 \frac{px}{a} + \frac{f^2 x^2}{4a^4} \cos^2 \frac{px}{a}}{\sin^2 \frac{pb}{a} + \frac{f^2 b^2}{4a^4} \cos^2 \frac{pb}{a}} \right\}^{\frac{1}{2}}$$

where γ is the amplitude of the specimen measured at the point where the string is connected, and f is the coefficient of friction of the string. This expression takes its greatest value obviously when

$$\sin \frac{pb}{a} = 0.$$

that is to say, when the point of application of the impressed force is a node, the amplification of the forced vibration attains its maximum value.

Preliminary Experiments.

To test the arrangement, the following experiment was made with a tuning-fork of known frequency, giving the following result.

Tuning-fork. Sol. 384 vs.							
$W=40.595$ grams. $w=4.77 \times 10^{-4}$ g/c. $g=979.8$ c/s ² .							
	1 st Obs.	2 nd Obs.	3 rd Obs.	4 th Obs.	Mean.	l'	calculated.
1 st Node.	24.0	24.1	24.1	24.0	24.0	24.00	24.0
2 nd Node.	47.7	48.4	48.0	47.9	47.9	23.95	47.8
3 rd Node.	71.6	71.6	71.4	71.4	71.5	23.83	71.6
4 th Node.	95.1	95.8	95.2	95.6	95.4	23.85	95.4

It is easy to see that a nodal point lies somewhere at a point near the origin of the scale-measurement. Let this distance be denoted by a , then the above values of l' corresponds to $l + \frac{a}{N}$ where N is the number of loops contained in the observed segment of the string. Thus a and l being two unknown quantities, they may be easily calculated by the method of least squares. The result is:—

$$a = 0.24$$

$$l = 23.89$$

whence we have

$$n = 191.9.$$

The correction for stiffness, which is inversely proportional to the fourth power of l , is insensibly small in this case.

The result of second experiment with the other string and smaller tension is

$$W = 20.908$$

$$w = 5.27 \times 10^{-4}$$

$$l = 16.32$$

whence $n = 191.6$

The difference between the two and the registered value 192 is within the error of observation.

As to the verification for the condition of a clamped end, the case of tuning-fork with two prongs is wholly out of place: so that the following observations with a prism of soft iron may not be superfluous to be cited here. Everything concerning a specimen being given, the frequency varies inversely as the square of the length of the vibrating portion; consequently the fixedness of the clamped section is very important. In the case of tuning-fork, the matter is somewhat different. Any continuation of the specimen beyond the clamped section would be without effect, as it acquires no motion; but as the first clamp is relaxed, the pitch rapidly falls, in consequence of the increase in length. Thus, in tapping the specimen care must be taken to give no impact to the clamped section, i.e. the specimen should be tapped at a place corresponding to the centre of percussion with respect to the clamped section.

The result of the first observation is as follows:—

$$\rho = 7.779$$

$$b = 0.763$$

$$L = 13.4$$

$$W = 30.718$$

$$w = 5.19 \times 10^{-4} \text{ g./c.}$$

$$E' = 1.221 \times 10^{12}$$

$$\rho' = 8.667$$

$$l = 10.87$$

whence $n_1 = 350.3$

$$n_2 = 0.2$$

$$n = 350.5$$

$$E = 2.029 \times 10^{12} \text{ c.g.s. unit.}$$

The result of the second observation with another string and smaller tension, in which the direction of motion of the point of attach-

ment was parallel to the length of the string* is as follows:—

$$W = 11^{\circ}.065$$

$$w = 5.67 \times 10^{-4} \text{ g/c.}$$

$$l = 12^{\circ}.47$$

whence

$$n_1 = 175.3$$

$$n_2 = 0.2$$

$$n = 351.0$$

$$E = 2.034 \times 10^{12} \text{ c.g.s. unit.}$$

The results obtained in the two different modes of experiment agrees with each other within the error of observation.

The experiments with sandstone and tuff, however, gave very ambiguous results to confound the observer. At first sight, it seems as if there were no definite length with which the string vibrated with maximum amplitude. For instance, in the case of sandstone, the length corresponding to maximum amplitude were as follows:—

9.28 ⁽¹⁾	9.93 ⁽¹⁾	10.64 ⁽¹⁾	11.42 ⁽¹⁾	12.24 ⁽¹⁾	13.40 ⁽¹⁾	14.63 ⁽¹⁾
16.23 ⁽¹⁾	17.39 ⁽²⁾	18.41 ⁽²⁾	19.69 ⁽²⁾	21.04 ⁽²⁾	22.61 ⁽²⁾	24.49 ⁽²⁾
26.06 ⁽³⁾	26.76 ⁽²⁾	27.58 ⁽³⁾	29.43*	31.53 ⁽³⁾	32.53 ⁽²⁾	33.89 ⁽³⁾
34.62 ⁽⁴⁾	36.76*	39.31 ⁽⁴⁾	40.00 ⁽³⁾	41.88 ⁽²⁾	43.08 ⁽⁵⁾	

Small number in brackets is the number of loops contained in the segment. Those marked with* correspond to a peculiar mode of vibration.

The first adequate supposition is that the elasticity of such loose materials as rocks which compose the earthcrust is not unique, so that they may vibrate with several distinct periods differing from each other. Further it becomes a matter of course that the velocity of propagation of seismic waves is not unique even for a given rock. Taking the case of sandstone No. 3₄, the half wave length with which the string may vibrate with maximum amplitude is either of the following numbers.

13.48 15.33 16.36 17.20 19.25 21.68 24.67 28.72 34.82 42.89.

* Note that, under these circumstances, the period of the string is *double* of that of the specimen, i.e. the frequency n of the specimen is equal to twice the frequency ($n_1 + n_2$) of the string.

If we assume that all these lengths equally correspond to proper vibration of the specimen, the period of vibration will not be unique but proportional to the above numbers. The velocity of longitudinal wave should be, then, proportional to the following series of numbers:—

12.9 11.3 10.6 10.1 9.0 8.0 7.0 6.0 5.0 4.0

In Professor F. Ōmori's papers we frequently find what correspond to the above, relating to the periods and velocities of seismic waves in their successive phases.

Repeated experiments, however, showed that such a multiplicity is the effect of tapping by the hammer, so that varying the period of the impressed force we might obtain another series of maximum values. I do not say that the same explanation may be applied to the case of seismic waves. It may be noted, however, that provided two neighbouring localities have their own periods of free vibration, similar phenomenon may possibly occur as one locality is shaken, forced by the motion of the other locality.

Although the vibration is essentially of free nature, it is rendered intermittent by the periodic interposition of an obstacle, so that a very different result is arrived at. In this case, a vibration of frequency n varies in its amplitude with a frequency m , the last of which being the frequency of the hammer. The amplitude increases very suddenly and it is always positive, so that the motion may be assumed, though in very rough approximation, to be represented by the expression, omitting a constant factor,

$$y = \{ \cos 2\pi mt \}^{1/2} \cos 2\pi nt.$$

By ordinary trigonometrical transformation, the above expression may be put into the form

$$y = A_0 \cos 2\pi nt + \sum_{v=1}^{v=a} A_v \{ \cos 2\pi(n+2vm)t + \cos 2\pi(n-2vm)t \}.$$

Thus, it is clear that, in such a case, the amplitude takes its maximum value, provided the length of the string corresponds to any one of the numerous component vibrations.

It will be easily seen that the relative magnitudes of the several

maximum amplitudes are very different from each other in such a way that the greatest maximum corresponds to the vibration with natural period of the specimen and the smaller the amplitude the more affected by the impressed force. When m is not too small to be compared with n , each maximum may be distinctly observed; but these consecutives more and more approach each other as the ratio $\frac{m}{n}$ becomes smaller and smaller. In the case where the ratio is one-fiftieth or smaller than that, the series of maxima become approximately continuous and practically constitute one maximum with small gradient.

Again, varying the period of the impressed force from m to m' , all the lengths corresponding to maximum amplitudes, except that which corresponds to the natural period of the specimen, are changed. When these two facts are taken into account, it is not difficult to determine that natural period of vibration for any specimen at hand.

Let l_a and l_b be the length of string, vibrating with one loop, corresponding to the numbers of vibration $(n+2am)$ and $(n+2bm)$ respectively, then for certain length l , which is a common multiple of l_a and l_b , the string vibrates in a peculiar manner apparently with one loop, nodes of one mode of vibration being overlapped by loops of other mode and vice versa.

One example will suffice to explain the method of experiments. In the case of sandstone, the result of one experiment with a brass hammer showed that the string might vibrate with maximum amplitude corresponding to any one of the numbers of vibration

$$410.0 \pm 25.7\nu$$

where ν is an integer, so that

$$n = 410.0$$

$$2m = 25.7.$$

Other experiment with a lead hammer, in which the moment of inertia was increased, gave other result as follows:—

$$n = 409.3$$

$$2m = 15.3$$

These two values for frequency in free vibration are equal to each other within the error of observation.

In the above observations, the tension of the string remained constant and equal to

$$W=30.718 \text{ grams.}$$

To test whether the error of observation is affected by the variation of the constant tension or not, other two observations were made on the same specimen, giving the result

$$\text{for } W=20.908 \quad , \quad n=411.4$$

$$\text{for } W=11.065 \quad , \quad n=409.1.$$

Now, taking the mean of the above four values, the data required to calculate the modulus of elasticity of the sandstone are

$$L = 9.9$$

$$h = 1.16$$

$$\rho = 2.25$$

$$n = 410.0$$

whence $E = 10.36 \times 10^{10} \text{ c.g.s. unit.}$

Experimental Result.

The above rather complicated method of observation was applied to determine the modulus of elasticity for one hundred fifty eight different specimens of rocks, containing 23 archæan, 65 palæozoic, 12 mesozoic and 58 cainozoic rocks. The following table gives the result, arranged in the order of geological age; for the same geological age, those with larger values for the modulus come before those with the smaller. For the complete discussion of the elastic nature of these rocks, so many different elastic constants as the number of symmetry planes, which can be drawn in these rocks, must be determined. As we have, however, no simple means of examining these symmetry planes, a single modulus of elasticity is determined relating to two mutually perpendicular directions, on the supposition that the material is isotropic. The velocity for longitudinal waves, calculated by the formula

$$V = \sqrt{\frac{E'}{\rho}}$$

is also given in the table. The value given in the table may be different from the actual one of longitudinal waves in various rocks, but it will probably give a rough estimate in so far as our modern seismometry is concerned.

KINETIC MODULUS OF ELASTICITY OF ROCKS.

(158 Specimens).

Specimen No.	Rock.	Locality.	Kind.	Density.	Kinetic modulus of elasticity.			Velocity of longit. wave.
					E_1	E_2	E	
ARCHÆAN ROCKS.					{c.g.s. $\times 10^{11}$ }	{c.g.s. $\times 10^{11}$ }	{c.g.s. $\times 10^{11}$ }	{Km./sec.}
5*	Chlorite schist.	Chichibu.	Metamorphic.	2.93	9.79	12.39	11.09	6.12
2*	Chlorite schist.	Chichibu.	Meta.	2.98	10.69	10.88	10.78	6.02
7 ₂	Peridotite.	{Machiya, Kuji. Ibaraki.	Eruptive. (Altered).	2.61	7.72	9.74	8.73	5.78
8 ₁	Serpentine.	Yokose, Chichibu.	Erup. (Altered).	2.72	9.05	6.98	8.02	5.43
46 ₁	Quartz schist.	Kashiwagi, Gunma.	Meta.	2.64	5.99	8.91	7.45	5.31
31 ₁	Quartz schist.	Onishi, Gunma.	Meta.	2.67	7.96	7.19	7.43	5.28
18 ₁	Chlorite schist.	Nogami, Chichibu.	Meta.	2.88	6.59	7.19	6.89	4.89
16*	{Peridotite serpentine	Mito, Ibaraki.	Erup.	2.83	6.55	7.97	6.81	4.91
22 ₁	Gabbro.	Nogami, Chichibu.	Erup.	2.71	5.95	7.26	6.61	4.94
26 ₂	Chlorite schist.	{Kunikami, Chichibu.	Meta.	2.87	5.21	6.35	5.78	4.49
31 ₁	Chlorite schist.	Chichibu.	Meta.	2.88	5.78	5.37	5.58	4.41
45 ₁	Chlorite schist.	Nogami, Chichibu.	Meta.	2.77	5.46	5.51	5.50	4.46
26 ₁	Chlorite schist.	{Kunikami, Chichibu.	Meta.	2.82	5.55	5.35*	5.45	4.39
28	Graphite schist.	Onishi, Gunma.	Meta.	2.59	5.39	5.07	5.23	4.50
41 ₁ *	{Peridotite serpentine.	Kuji Ibaraki.	Erup.	2.78	5.13	4.93	5.04	4.27
24 ₁	Graphite schist.	{Kunikami, Chichibu.	Meta.	2.59	4.88	5.15	5.02	4.41
49 ₁ *	Chlorite schist.	Nogami, Chichibu.	Meta.	2.77	4.84	5.00	4.92	4.22
41 ₂ *	{Peridotite serpentine.	Kuji, Ibaraki.	Erup.	2.79	4.52	4.86	4.69	4.10
60 ₁	Gneiss.	Shinshiro, Mikawa.	Meta.	2.59	4.92	4.98	4.50	4.17
17*	{Peridotite serpentine.	Ibaraki.	Erup.	2.57	4.21	4.67	4.44	4.16
47 ₁	Quartz schist.	Onishi, Gunma.	Meta.	2.63	4.82	3.31	4.08	3.94
23 ₁	Graphite schist.	{Kunikami, Chichibu.	Meta.	2.56	4.05	4.02	4.04	3.98
39	Chlorite schist. (Decomposed).	Onishi, Gunma.	Meta.	2.64	3.96	4.11	4.03	3.91

Specimen No.	Rock.	Locality.	Kind.	Density.	Kinetic modulus of elasticity.			Velocity of longit. wave.
					E_1	E_2	E	
PALÆOZOIC ROCKS.								
67 ₁	Schalsteine.	Asama, Ise.	Sedimentary.	2.98	9.35	9.50	9.62	5.68
12 ₂	Clay slate.	Miyanomai, Aumi.	Sed.	2.71	9.26	8.84	9.05	5.78
69 ₁	Pyroxenite.	Yamada, Ise.	Meta.	3.05	8.85	8.87	8.86	5.40
78 ₂ *	Schalsteine.	China.	Sed.	2.77	8.01	8.60	8.30	5.48
78 ₂ *	Schalsteine.	China.	Sed.	2.77	8.34	7.87	8.11	5.41
•								
65 ₁	Schalsteine.	Kamuro, Ki-i.	Sed.	2.84	8.32	7.80	8.06	5.33
71 ₁	Limestone.	Akasaka, Mino.	Sed.	2.71	7.82	7.54	7.68	5.33
32 ₁	Pyroxenite.	Mihara, Gumma.	Sed.	2.90	7.81	7.52	7.67	5.15
2 ₂ *	Clay slate.		Sed.	2.69	7.61	7.47	7.54	5.20
34 ₁	Adinol slate.	Yono-o, Gumma.	Sed.	2.64	7.54	7.45	7.20	5.33
•								
13*	Limestone.	Aome, Kanagawa.	Sed.	2.65	7.43	7.52	7.48	5.31
2 ₂ *	Clay slate.		Sed.	2.67	7.77	7.13	7.45	5.28
29*	Limestone.	Bukōzan, Mikawa.	Sed.	2.68	6.68	7.11	6.89	5.07
79*	Schalsteine.	Rikuchiu.	Sed.	2.65	6.75	6.70	6.72	5.04
74 ₁	Limestone.	Akasaka, Mino.	Sed.	2.69	6.66	6.65	6.65	4.97
•								
55*	Limestone.	Musashi.	Sed.	2.63	6.55	6.62	6.58	5.01
71 ₂	Limestone.	Akasaka, Mino.	Sed.	2.69	6.67	6.30	6.48	4.91
11 ₂ *	Marble.	Hitachi.	Sed.	2.63	6.28	6.14	6.20	4.86
73*	Sandy slate.	Rikuchiu.	Sed.	2.64	6.13	6.05	6.09	4.81
80*	Schalsteine.	Rikuchiu.	Sed.	2.82	5.77	6.23	6.00	4.62
•								
72 ₁	Limestone.	Akasaka, Mino.	Sed.	2.69	5.87	6.13	6.00	4.72
59 ₁	Granite.	Okazaki, Mikawa.	Erup.	2.63	5.92	5.94	5.93	4.75
74 ₂	Clay slate.	Nikkō, Tochigi.	Sed.	2.15	5.69	5.72	5.70	5.15
1 ₂ *	Weathered clay slate.		Sed.	2.31	5.13	5.93	5.53	4.80
87 ₁	Ophiolite.	Arakawa, Chichibu.	Erup.	2.65	4.91	5.30	5.11	4.39
•								
21 ₁	Limestone.	Nogami, Chichibu.	Sed.	2.64	5.31	4.76	5.04	4.37
1 ₂ *	Weathered clay slate.		Sed.	2.30	4.97	4.58	4.77	4.55
9 ₁	Granite.	Mikage, Hyōgo.	Erup.	2.54	4.88	4.61	4.75	4.32
76 ₁	Slate.	Atago, Kyōto.	Sed.	2.24	4.61	4.83	4.72	4.59
40 ₁	Micaschist.	Fudō-tōge, Ibaraki.	Meta.	2.54	4.25	4.81	4.53	4.22
•								
69*	Granite.	{Schōdō-Jima, Kugawa.	Eruptive.	2.57	4.53	4.42	4.47	4.17
81 ₁	Granite.	Tamba.	Erup.	2.62	4.46	4.46	4.46	4.13
64 ₁	Granite.	Nishiura, Mikawa.	Erup.	2.61	4.53	4.30	4.42	4.11
66 ₂	Granite.	Shirakawa, Kyōto.	Erup.	2.62	4.28	4.01	4.14	3.98
79 ₁	Slate.	Narutaki, Kyōto.	Sedimentary.	2.45	3.90	4.26	4.08	4.00
•								
75 ₁	Limestone.	Akasaka, Mino.	Sed.	2.72	3.55	4.59†	4.07	3.87
66 ₁	Granite.	Shirakawa, Kyōto.	Erup.	2.62	4.03†	—	—	3.93
6 ₃	Marble.	Maiyama Kuji.	Sed.(Metamorp.)	2.68	3.48	3.89	3.69	3.71
3 ₂ *	Clay slate.	Tamba.	Sed.	2.39	3.63	—	—	3.90
60 ₂ *	Weathered clay shale.	Yamashiro.	Sed.	2.31	3.65	3.49	3.57	3.94

Specimen No.	Rock.	Locality.	Kind.	Density.	Kinetic modulus of elasticity.			Velocity of longit. wave.
					E_1 .	E_2 .	E .	
44 ₁	Granite.	Hyōgo.	Erup.	2.59	3.49	3.33	3.41	3.63
63 ₂	Granite.	Nishiura, Mikawa.	Erup.	2.84	3.35	3.37	3.36	3.44
12 ₂ *	Marble.	Hitachi.	Sed.	2.65	3.35†	—	—	3.56
10 ₂	Granite.	Kitagi, Kagawa.	Erup.	2.57	3.24	—	—	3.55
63 ₁	Granite.	Nishiura, Mikawa.	Erup.	2.84	3.40	3.02†	3.21	3.36
60 _a *	{ Weathered clayslate.	Yamashiro.	Sed.	2.32	3.66	2.72†	3.19	3.72
3 ₂ *	Clayslate.	Tamba.	Sed.	2.38	3.17	—	—	3.65
78 ₂	Slate.	Narutaki, Kyōto.	Sed.	2.42	3.13	3.16	3.14	3.59
12 ₂ *	Marble.	Hitachi.	Sed.	2.65	3.68†	2.60†	3.14	3.44
78 ₁	Slate.	Narutaki, Kyōto.	Sed.	2.41	3.08†	—	—	3.55
80 ₁	Slate.	Atago, Kyōto.	Sed.	2.36	2.99	3.00	3.00	3.56
27 ₁	Micaschist.	{ Motoizumi, Chiehibu.	Meta.	2.63	2.71	3.15	2.93	3.35
29 ₁	Limestone.	Orishi, Gumma.	Meta.	2.66	2.40	2.85	2.63	3.15
64 ₁ *	Clayslate.	Iokura, Tochigi.	Sed.	2.46	2.63	2.46	2.54	3.21
82 ₁	Contact slate.	Tamba.	Sed.	2.33	2.55	2.23	2.49	2.97
68*	Granite.	Kitagi, Kagawa.	Erup.	2.55	2.19	1.67†	1.93	2.79
52*	Granite.	Fukuhara, Ibaraki.	Erup.	2.50	1.80†	—	—	2.68
7 _a *	{ Weathered clayslate.	Ōizumi, Hitachi.	Sed.	2.50	1.53	1.58	1.56	2.50
65 _a *	{ Weathered clayslate.	Ōizumi, Hitachi.	Sed.	2.49	1.54	1.53	1.53	2.48
7 _b *	{ Weathered clayslate.	Ōizumi, Hitachi.	Sed.	2.50	1.51	1.44	1.47	2.43
65 _b *	{ Weathered clayslate.	Ōizumi, Hitachi.	Sed.	2.50	1.38	1.37	1.37	2.34
56*	Granite.	Iwase, Ibaraki.	Erup.	2.52	1.36	1.20	1.28	2.25
71*	Granite.	Iwase, Ibaraki.	Erup.	2.59	1.28	1.23	1.25	2.20
42 ₁	Mica schist.	Tunkioke, Ibaraki.	Meta.	2.64	1.08	1.29	1.19	2.12
61 ₁	Pegmatite.	Hōjō, Ibaraki.	Erup.	2.57	1.16	1.10	1.13	2.10

MESOZOIC ROCKS.

53*	Clayslate.	Ishinomaki, Miyagi.	Sed.	2.79	7.80	7.39	7.59	5.30
77*	Schalsteine.	{ Akamagaseki, Nagato.	Sed.	2.78	6.46	6.52	6.49	4.85
72*	Clayslate.	Okatsu, Rikuzen.	Sed.	2.71	6.51	6.38	6.46	4.89
76*	Clayslate.		Sed.	2.71	6.42	6.38	6.40	4.87
62 _a *	Clayslate.	Tsushima.	Sed.	2.68	4.39	4.25	4.32	4.02
68 ₁	Granite.	Yoshima.	Erup.	2.61	3.42	3.40	3.41	3.62
5 ₂	Sandstone.	Wakayama.	Sed.	2.22	1.32	1.50	1.41	2.52
85 ₁	Sandstone.	Kinshiu.	Sed.	2.34	1.29	1.30	1.30	2.36
6 _b *	Sandstone.	Tanabe, Ki-i.	Sed.	2.22	1.23	1.00	1.11	2.23
83 ₁	Sandstone.	Kinshiu.	Sed.	2.09	1.03	1.07	1.05	2.24
84 ₁	Sandstone.	Kinshiu.	Sed.	2.24	1.02	1.05	1.03	2.15
6 ₂ *	Sandstone.	Tanabe, Ki-i.	Sed.	2.24	1.02	0.95†	0.98	2.09

Specimen No.	Rock.	Locality.	Kind.	Density.	Kinetic modulus of elasticity.			Velocity of long. wave.
					E_1 .	E_2 .	E .	
CAINOZOIC ROCK.								
51 ₁	Andesite.	Shinano.	Erup.	2.61	4.37	4.35	4.36	4.09
17 ₁	Andesite.	Horuna, Gumma.	Erup.	2.63	4.17	3.94	4.06	3.94
1 ₁	Andesite.	Nebukawa, Sagami.	Erup.	2.59	3.96	—	—	3.91
54*	Andesite.	Nebukawa, Sagami.	Erup.	2.56	4.12	3.53	3.83	3.87
35 ₁	Sandstone.	Mitagawa, Chichibu.	Sed.	2.47	3.65	3.41	3.53	3.78
1 ₂	Andesite.	Nebukawa, Sagami.	Erup.	2.59	3.45	3.59	3.52	3.69
15*	Andesite.	{ Motokomatsu, Sagami.	Erup.	2.20	3.32	3.10	3.21	3.82
52 ₁	Rhyolite.	Hōrai-ji, Mikawa.	Erup.	2.20	3.20	3.08	3.14	3.80
57 ₁	Porphyllite.	Gmi. Mikawa.	Erup.	2.29	3.31	2.92	3.12	3.70
51*	Rhyolite.	Honbun, Izu.	Erup.	2.32	3.12	3.10	3.11	3.66
50 ₁	Andesite.	{ Nakatsugarn, Mutsu.	Erup.	2.69	2.79	2.90	2.85	3.26
14*	Tuff.	Nanasawa, Sagami.	Sedi.	2.22	2.91	2.66	2.79	3.55
28*	Andesite.	Izu.	Erup.	2.17	2.49	2.87	2.68	3.52
30*	Tuff.	Kiga, Izu.	Sed.	2.17	2.51	2.64	2.57	3.45
8 _a *	Rhyolite tuff.	Iyo.	Sed.	2.35	2.48	2.36	2.42	3.21
39*	Andesite.	Yokone, Izu.	Erup.	2.40	2.39	2.35	2.37	3.14
10*	Tuff.	Yoshida, Izu.	Sed.	2.28	2.29	2.39	2.34	3.21
70*	Andesite.	{ Shiokomatsu, Sagami.	Erup.	2.46	2.40	2.23	2.31	3.07
58 ₁	Sandston.	Yebi, Mikawa.	Sed.	2.21	2.33	2.27	2.30	3.23
57 ₁	Rhyolite tuff.	Iyo.	Sed.	2.32	2.22	2.38	2.30	3.15
19 _c *	{ Tufaceous sandstone.	Tomioka, Kōtsuke.	Sed.	2.32	2.15	2.31	2.23	3.10
56 ₁	{ Tufaceous sandstone.	Yebi, Mikawa.	Sed.	2.12	2.17	2.12	2.15	3.19
63 _a *	Rhyolite tuff.	Nakura, Mikawa.	Sed.	2.15	2.15	2.11	2.13	3.14
19 _a *	{ Tufaceous sandstone.	Tomioka, Kōtsuke.	Sed.	2.31	2.08	2.01	2.04	2.97
59 _b *	Rhyolite.	Kōtsuke.	Erup.	2.45	1.94	1.93†	1.94	2.82
53 ₁	Rhyolite tuff. (Weathered)	Hōrai-ji, Mikawa.	Sed.	2.16	1.78	1.87	1.83	2.91
4 _a *	Tuff.	Kawatsu, Izu.	Sed.	1.84	1.78	1.84†	1.81	3.14
59 _a *	Rhyolite.	Kōtsuke.	Erup.	2.47	1.88	1.64	1.76	2.67
67 _a *	Andesite tuff.	{ Kami-midera, Yechizen.	Sed.	2.44	1.74	1.73	1.73	2.66
57*	Tuff.	Nawazi, Izu.	Sed.	2.04	1.67	1.70†	1.69	2.88
6, 7*	Andesite tuff.	{ Kami-midera, Yechizen.	Sed.	2.40	1.63	1.72	1.68	2.65
54 ₁	{ Tufaceous sandstone.	Hōrai-ji, Mikawa.	Sed.	2.07	1.55	1.63	1.59	2.77
46 _b *	Andesite.	Manazuru, Sagami.	Erup.	2.55	1.56	1.55	1.55	2.47
2 ₁	Tuff.	Kawatsu, Izu.	Sed.	1.91	—	1.50	—	2.80
40*	Andesite.	{ Haku-chōba, Sagami.	Erup.	2.30	1.54	1.45	1.49	2.54

Specimen No.	Rock.	Locality.	Kind.	Density.	Kinetic modulus of elasticity.			Velocity of long. wave.
					E_1 .	E_2 .	E .	
61*	Rhyolite tuff.	Iwashiro.	Sed.	2.20	1.46	1.48	1.47	2.59
36*	Tuff.	Izu.	Sed.	1.85	1.65	1.27	1.46	2.81
49*	Andesite.	Mikura, Izu.	Erup.	2.21	1.46	1.39	1.42	2.54
4*	Tuff.	Kawatsu, Izu.	Sed.	1.82	1.45	1.39	1.42	2.79
55 ₁	Tufaceous sandstone.	Hōrai-ji, Mikawa.	Sed.	2.09	1.44	1.35	1.39	2.53
47*	Andesite.	Yenoura, Shiraga.	Erup.	2.43	1.36	1.35	1.35	2.36
61 _a *	Rhyolite tuff.	Iwashiro.	Sed.	2.23	1.37	1.30	1.34	2.45
22*	Tuff.	Izu.	Sed.	2.01	1.30	1.35	1.32	2.56
58*	Sandstone	Chōshi, Chiba.	Sed.	2.35	1.35	1.26	1.30	2.35
5 ₂	Rhyolite.	Midera, Yechizen.	Erup.	2.40	1.09	1.23	1.18	2.22
16	Andesite	Haruna, Gumma.	Eruptive.	2.32	1.21	1.14	1.18	2.26
32*	Rhyolite tuff	Mitaka, Izu.	Sed.	1.89	1.21	1.02	1.11	2.42
37*	Quartz sandstone.	Hizen.	Sed.	2.23	1.02	1.21	1.11	2.23
38*	Andesite.	Katsurugi, Izu.	Erup.	1.94	1.05	1.17	1.11	2.39
4 ₃	Sandstone.	Tanabe, Kii.	Sed.	2.25	1.04	1.13	1.08	2.19
23*	Andesite tuff.	Yema, Izu.	Sed.	1.83	1.00	0.98	0.99	2.33
34*	Andesite.	Manazuru, Sagami.	Erup.	2.02	0.96	0.95	0.95	2.17
66*	Rhyolite tuff.	Amakusa, Hizen.	Sed.	2.26	0.96†	0.62†	0.79	1.87
31*	Tuff.	Teishi, Izu.	Sed.	1.92	0.78	0.77	0.78	2.02
48*	Andesite.	Izu.	Erup.	2.10	0.63	—	—	1.73
3 ₂	Sandstone.	Chōshi, Chiba.	Sed.	2.20	0.56	0.62	0.59	1.63
21*	Andesite tuff.	Izu.	Sed.	1.50	0.42	0.50	0.46	1.76
35*	Tuff.	Izu.	Sed.	1.29	0.26†	—	—	1.43

N.B. The specimens marked with * are those whose elastic constants were already determined by Professor H. Nagaoka, following a statical method, and published in Pub. of the E. I. C. in F. L. No. 4 1900; Phil. Mag. Vol. 2. July, 1900.

The specimens marked with † are those which were found to have been broken in their clamped portion during the experiment, so that the values given in the table are probably more or less erroneous due to imperfect clamping.

General Conclusion.

Representing the elastic constant of rocks, classified according to the age of formation, by means of "the height from a fixed base line," Fig. 2, Pl. II, we find a distinguished gradation as we pass from the rocks of archæan age to those of cainozoic. Some of recent age may, of course, have greater modulus of elasticity than those belong-

ing to older period. As a whole, however, archaean rocks come in the first of all, while cainozoic rocks come in the last.

In so far as the present experiments go, the greatest and the least of one group are respectively greatest than those of more recent group in turn. Even for a given rock, the modulus seem to become less for that of recent formation. To take an example, of palaeozoic rocks, the mean value for six specimens of schalsteine and fourteen specimens of granite of various localities are

$$E=7.80 \times 10^{11}$$

and $E=3.60 \times 10^{11}$ c.g.s. unit respectively, while for the specimens of schalsteine and granite of mesozoic age, the modulus is

$$E=6.47 \times 10^{11}$$

and $E=3.41 \times 10^{11}$ c.g.s. unit respectively.

The modulus of elasticity for a given rock may also vary within wide limits, as density and other physical properties differ for each specimen. For instance, in the case of granite, a specimen from Okazaki in Mikawa District has

$$E=5.93 \times 10^{11}$$

while that from Iwase in Ibaraki prefecture has only

$$E=1.25 \times 10^{11} \text{ c.g.s. unit.}$$

It must not, however, be misunderstood that the specimens from two different localities have necessarily different values. In the case of schalsteine, e.g., a specimen from China has

$$E=8.11 \times 10^{11}$$

while that from Kamuro in Kii District has a nearly equal value

$$E=8.06 \times 10^{11} \text{ c.g.s. unit.}$$

For engineers, it should be well remarked that any more compact specimen which has greater density has not necessarily greater modulus of elasticity. For instance, in the case of Andesite, "Honkomatsu-Ishi" from Sagami District has its modulus of elasticity thirteen per cent greater than "Kauehira-Ishi" from Mutsu District, while the latter has its density twenty-two percent greater than the

former. Again, a piece of granite from Nishiura in Mikawa District has its density twelve per cent greater than that from Mikage, while the latter has its modulus of elasticity, on the contrary, forty-eight per cent greater than the former. That a material has greater modulus of elasticity and yet less density is what makes it more valuable.

As a general rule, however, rocks of recent formation have less modulus of elasticity and, at the same time, less density than those of old period. The modulus of elasticity of old rocks increase very rapidly, more rapidly, indeed, than proportional to, as the density increases slowly. In Fig. 3, Pl. I. the modulus of elasticity of 158 specimens is plotted against the density of corresponding rocks.

Velocity of propagation for longitudinal waves, as shown in the above table, also increases with age of formation of the rock in reference. It may be noted here that, in so far as the present experiments go, the curve expressing the relation between the density and the velocity is somewhat concave towards the positive part of the axis along which the velocity is measured.

Effect of Moisture.

The present arrangement being unsuitable to give desired moisture to the specimens, it is only intended to test whether the modulus of elasticity is or is not largely affected by the degree of moisture of the specimen.

In the first case, a specimen of sandstone was clamped in the usual way, and the wire stretched with a known tension. When the specimen was in ordinary dry state, it was found that the wire vibrated most violently when the half wave length was 10".39. Then the specimen was wrapped with a wet cloth in its clamped state and fed with a constant supply of water drops during forty-two hours to get wet throughout. Now it was found that the corresponding half wave length increased to about a double, i.e. 20".25, which indicated that the modulus of elasticity decreased to about one-fourth of its original

value! Not without some doubt on the result, the author waited a whole day till the specimen became apparently dry. Then, the specimen nearly returned to its original state of elasticity, so that the corresponding half wave length decreased to 10°.65. Heating the specimen by hot air to drive all the moisture, and then cooling it into ordinary temperature, its elasticity increased slightly, the corresponding half wave length becoming equal to 9°.89. After three hours, the half wave length increased to 10°.62, showing that the modulus of elasticity was somewhat weakened, returning to its ordinary moisture. The result of such cyclical observations shows clearly that the enormous diminution of the modulus of elasticity by the effect of moisture is an actual fact. The difference between the initial value 10°.39 and the final value 10°.65 may be due to some variations of other conditions,—probably a little relaxation of the clamp. As the first clamp is relaxed, it results in the increase of the effective length of the specimen. The last difference corresponds to an increase of about one mm. in the effective length. The following result of experiment may serve to give a rough notion relating to the effect of moisture.

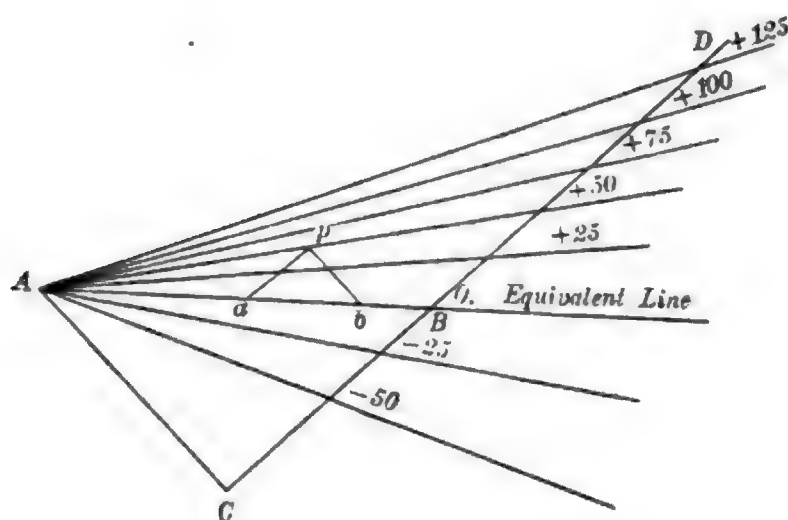
Rock.	Kind and Age.	When it is dry.	When it is wet.
Sandstone.	{ Sedimentary, Mesozoic.	$\rho_1 = 2.230, E_1 = 10.15 \times 10^{10}$	$\rho_2 = 2.351 E_2 = 3.173 \times 10^{10}$
Micaschist.	{ Metamorphic, Palaeozoic.	$\rho_1 = 2.647, E_1 = 17.54$	$\rho_2 = 2.669 E_2 = 9.21$
Serpentine.	{ Eruptive, Archæan.	$\rho_1 = 2.708, E_1 = 74.55$	$\rho_2 = 2.711 E_2 = 62.83$

The above table will teach us at a glance how an important part on the elastic nature of the earthcrust the water plays, which may permeate the earth's surface. To study more closely the effect of humidity, and especially its effect as combined with high temperature, a

special arrangement is now in preparation, and I hope to be able to write some results on the subject in the near future.*

Relation between the Kinetic and the Static Moduli.

Of 158 specimens given in the above table, a greater part have their elastic constants determined in a statical way, by either Prof. H. Nagaoka or the author himself. Now it is of no small interest to compare the kinetic and the static values for one and the same specimen of rocks.



* The remarkable influence of moisture on the elastic behaviour of rocks, which are not generally deeply embedded in the earth's crust, offers an interesting inquiry into some of the local shocks of earthquakes. With the prevailing rainy weather, there is possibility of the surface rocks being soaked with water. With decreased elastic constants and probably with decreased tenacity, the upper layer of the earth's crust will be subject to increased strain. This evidently will have a tendency to cause rupture, and give rise to feeble local shocks or tremors. The effect will be more felt in regions where the stress distribution is not uniform and the surface stability insecure. It will be of no small interest if such feeble local shocks are to be traced after a long succession of rainy days.

According to the investigations of Mr. Nakamura and Mr. Honda, the level of underground water is affected by the barometric pressure in a most striking manner. Its subsidence and upheaval will to some extent contribute to the variation in the elastic deformation of the surface layers, due to the cause above alluded to. It is however questionable if the variation of the elastic moduli due to moisture arising from this change makes itself felt as tremors or feeble local shocks. H. Nagaoka.

Here a short remark may be added relating to a new system of co-ordinates specially fitted for percentage representation. Take a right-angled isosceles triangle ABC with its vertex C below the horizontal base AB . Divide the base AB and one side BC into one hundred equal segments, and also in the produced part BD mark off any number of segments equal to one of the last. Join the vertex A with each of the points of section on the side BC and its produced part BD .

Let α and β be the corresponding values of any physical quantity in two different conditions $\mathfrak{A}$ and $\mathfrak{B}$. From A as origin, measure a length equal to α on the side AC or its produced part, then from the end point measure again a length equal to β in the direction parallel to the other side CB . If the last point falls on the base AB , the physical quantity is invariable in the two conditions. If the point, on the other hand, falls on the n^{th} of the previously drawn lines, numbered from the base AB which may be called "equivalent line," then the physical quantity is increased or decreased n percent while the conditions varies from $\mathfrak{A}$ to $\mathfrak{B}$, according as the line is above or below the equivalent line.

In this new system of co-ordinates, the radius vector and the percentage may be considered as two independent variables. This system of co-ordinates somewhat resembles the polar co-ordinates, but one variable "percentage" is not proportional to an angle measured from any fixed line. If a point p (ρ, n) is given, then describe a rightangled isosceles triangle apb , with the given point as vertex and its base ab coinciding with the equivalent line AB . The two segments Aa and Ab represents the corresponding values in two different conditions referred, in a unit multiplied by $\sqrt{2}$.

In Fig. 4, the modulus of elasticity is represented in this co-ordinate system, its static and kinetic values corresponding to α and β of the above illustration respectively. It will be seen, at a glance, that when the radius vector is relatively small, almost every point lies on the positive side, while a greater part of those for which the radius vector is somewhat greater lies on the negative side. General-

ly speaking, in so far as the present experiment goes, the percentage is enormously great for small radius vector, but it diminishes as the radius vector increases and ultimately it becomes negative. That the percentage diminishes as the radius vector increases is a matter of course, in so far as the phenomenon of yielding is the principal cause which make the two values different from each other. The negative value, however, can never be expected unless some other cause or causes there exist beside the phenomenon of yielding.

Examining more closely, we see that the percentage rapidly diminishes and becomes even negative especially for those rocks which have distinct sedimentation planes as schists and slates. In schistose rocks, the percentage is generally negative, as they have large modulus of elasticity and, at the same time, distinct sedimentation planes. Eruptive rock of any age, be it caenozoic or archæan, has positive percentage. Of sedimentary rocks, those whose modulus of elasticity are comparatively small have also positive percentage, but some of them having large modulus of elasticity may have negative percentage. The following table will show the fact more clearly :—

Rock.	Kind.	Total number of observed specimens.	Mean value of their percentage.	Mean value of their modulus of elasticity.
Sandstone.	Sedimentary.	6	+38	1.57×10^{11} cgs.
Tuff.	Sedimentary.	7	+23	1.92
Andesite.	Eruptive.	13	+20	2.12
Granite.	Eruptive.	5	+11	3.14
Slate.	Sedimentary.	17	-6	4.69
Peridotite and serpentine.	Eruptive.	6	+4	6.29
Schists.	Metamorphic.	10	-10	6.39

Here it must be noted that I do not mean to say that the percentage would be always negative for any old rock having distinct sedimentation planes. With all probability, it would be true that the percentage diminishes as the radius vector increases; becoming negative,

however, may be due to some other causes. The two series of observations have been made with widely different surrounding conditions. The effect of humidity and temperature, for instance, is never negligible, as some of observations were conducted during wet and hot seasons while the other during dry cold season.

Any complete discussion of the relation between the static and the kinetic values must be postponed, at least, until the effect of temperature and humidity on the elastic constants are clearly investigated. The numerical values given above as modulus of elasticity of several rocks, as well as those given in other works, unless the corrections due to temperature and humidity were taken into account serve for nothing more than to give a rough estimation—too rough to compare the results of any two series of observations.

The only conclusion to be properly given is that the result of experiments has only brought him, who thought it at first sight to be a quarry of research that would soon suffer exhaustion, to the threshold of new labyrinths, where he may find innumerable paths to proceed further. The whole series of observations hitherto made is, indeed, but a beginning in this field of inquiry, and for all the trouble and labour expended to obtain but a poor result, the author is consoled with the saying of Boyle, "men being oftentimes obliged to suffer as much wet and cold and dive as deep to fetch up sponges as to fetch up pearls."

In conclusion, I wish to express my great indebtedness to Dr. Fukuchi, Lecturer in Geological Institute, for valuable informations concerning the geological characters of the specimens. My best thanks are due to Professor H. Nagaoka under whose kind guidance I carried out this experiment.

MARCH 1905.

PHYSICAL LABORATORY, COLLEGE OF SCIENCE,
IMPERIAL UNIVERSITY OF TŌKYŌ.

Fig. 10.



Fig. 11.

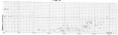
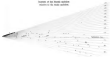
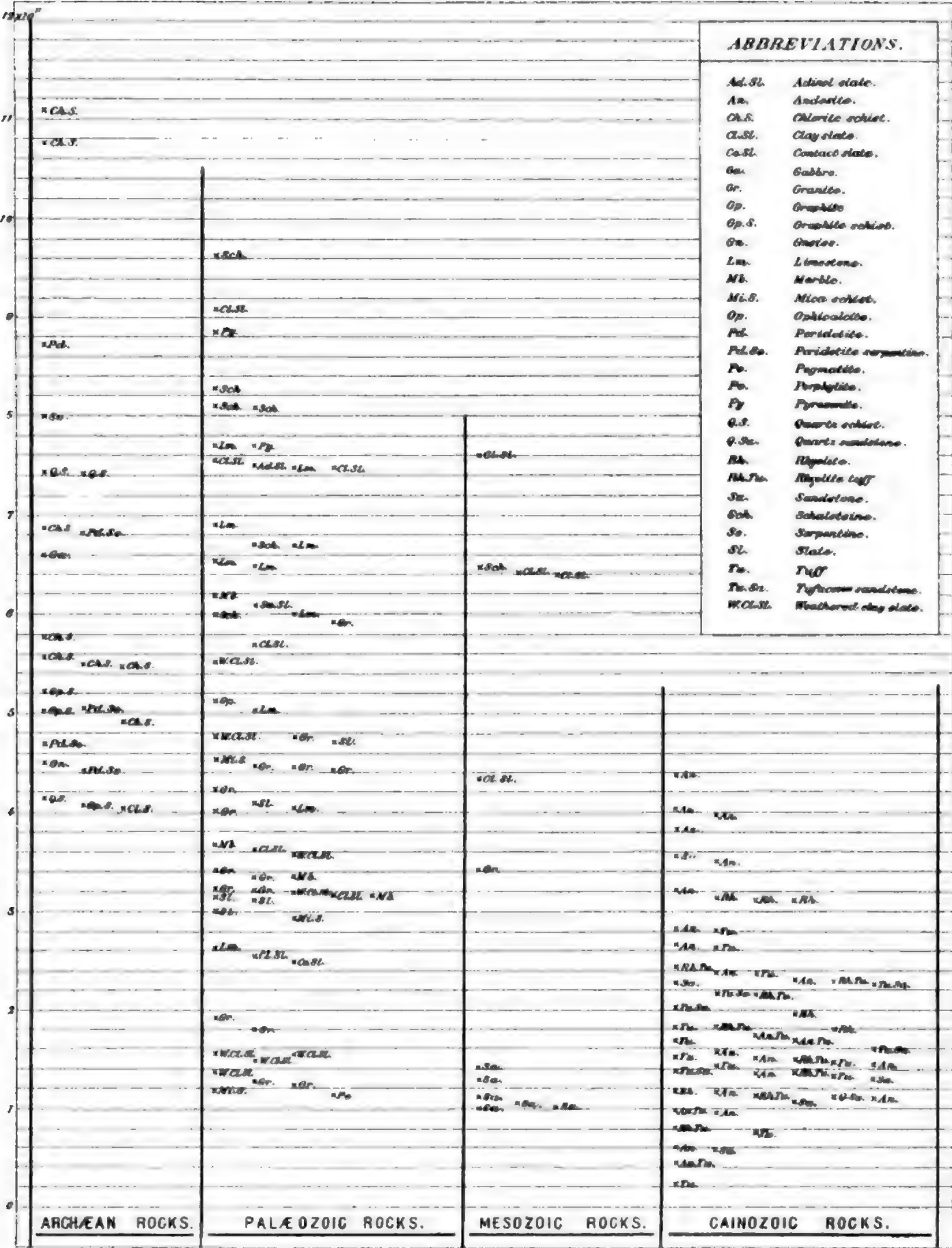


Fig. 12.
Diagram of the sound system
showing the sound system.



Art. 3, Kusakabe, Pl. II.
Modulus of Elasticity.



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印刷者 島 連太郎

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TŌKYŌ, 1906.

On the Geyser in Atami.

BY

K. HONDA and T. TERADA.

Lecturers of Physics, Tokyō Imperial University.

With Plates I-XII

I. INTRODUCTION.

The remarkable feature of the periodic eruptions of geysers has attracted the attention of many observers. Mackenzie,¹⁾ who travelled in Iceland in 1811 and observed the Great Geyser, first tried to explain the phenomenon; but his theory proved unsatisfactory. Bunsen,²⁾ travelling on the same island in 1847, made observations on the Great Geyser, and explained the phenomenon by his well-known theory of the vertical pipe. According to him, the origin of the eruption lies in the lower part of the vertical pipe which does not exceed 20m in the case of this geyser. Müller³⁾ constructed a model after Bunsen and showed that it works periodically, if two portions of the vertical pipe be heated. His theory, however, is not free from objections. Contrary to the Bunsen's view, O. Lang⁴⁾ considered the seat of the eruption to lie at a great depth in a canal connected with the vertical one, the water in which acts as a valve for the enclosed vapour. Models given by Julius Ziegler⁵⁾ and by G. Wiedemann⁶⁾ explain the

1) Mackenzie, *Travels in Iceland*, 1811.

2) Bunsen, "Physikalische Beobachtungen über die hauptsächlichsten Geysir, Islands," *Gehlers Physikalisches Wörterbuch* (2te Auflage), LXXII; *Pogg. Ann.*, 72, 1847.

3) Müller, *Lehrbuch der Kosmischen Physik*, Braunschweig, 1894, S. 619.

4) O. Lang, "Ueber die Bedingungen der Geysir," *Göttinger Gelehrten Nachrichten*, S. 225.

5) Ziegler, *Vorträge des phys. Vereins in Frankfurt a. M.*, 1872, demonstrated by Dr. Nippoldt.

6) G. Wiedemann, "Ueber einen Apparat zur Darstellung der Erscheinungen der Geysir," *Ann. der Phys. u. Chem.* (2), 12.

phenomenon of the geyser from similar points of view. The models consist of a vertical pipe and a large cavity containing hot water and connected to a water tank placed at a suitable height. The constant heating of the cavity produces periodic eruptions of water and steam. Models constructed by J. Petersen, A. Andreae and others¹⁾ do not differ much in principle from those just referred to. The experimental investigations by Andreae²⁾ and E. Ebert³⁾ shew that by proper modification of different parts of the models, the several types of eruptions observed in natural geysers can easily be imitated; but the latter remarks that it seems difficult to explain by such a simple theory all the diversities of the manner of eruptions observed in numerous geysers in Iceland, North America and New Zealand.

In Japan, we have two geysers, one at Atami and another at Onikôbe, the force of eruption of the latter being very weak. Twenty years ago, we had another one in Noboribetsu in Hokkaidô, the eruption of which is said to have recurred a few times per hour, projecting hot water a few meters above the ground. At present, it has completely lost its periodical character.

The geyser of Atami is situated on the eastern slope of the coast mountain range of Izu. Its orifice is about 1 km distant from the sea shore and about 22 m above the sea level. Differing from other geysers, the geyser of Atami is characterized by the regularity of its eruption, which consists of alternate projections of hot water and steam, usually five times in succession. The orifice, which originally opened vertically upward, has been covered by a heap of stones to prevent the dangers caused by the eruption, and directed horizontally, so that

1) J. Petersen, "Darstellung der Geysir Erscheinungen," *Neues Jahrbuch für Mineralogie, Geologie u. Palaeontologie*, 1879, 2.

A. Andreae, "Ueber einen künstliche Nachbildung der Geysir-phänomene," *ibid.*, 1893, 2.

K. Antolik, *Zeitschrift f. d. phys. u. chem. Unterricht*, 1890-91.

A model given by A. C. Munby, *Nature*, LXV, p. 247, is of a somewhat different principle.

2) A. Andreae, *loc. cit.*

3) H. Ebert, "Versuch mit dem G. Wiedemannschen Geysir-Apparat," *Ann. d. Phys. u. Chem.* (2), LXIII.

the water projected does not return to the mouth, as it does in many other geysers. At present, three orifices (A, a, a', Pl. I) are exposed, among which the one (A) is to be distinguished as the principal opening. There is besides, another mouth, hidden underground. The water projected by these orifices is distributed to numerous bath-houses by a system of conduits.

According to the result of the analysis by Dr. Martin in 1874 and by Dr. Tawara in 1883, the mineral constituents of the water of the spring in 1 litre are as follows;—

Mineral constituents	Martin	Tawara
Solid residuals	10.0104 gr.	9.235 gr.
Sodium chloride	3.79	5.409
Potassium chloride	1.81	0.354
Calcium chloride	1.767	2.893
Magnesium chloride	2.333	0.0145
Calcium sulphate	0.193	0.1313
Ferrous bicarbonate	0.0031	0.002
Calcium bicarbonate	0.0042	trace
Silica	0.110	0.5249
Manganese chloride	trace	trace
Sodium bromide	"	"
Potassium bromide	"	"

The water is of a strong saline taste, containing about $\frac{1}{2}$ percent of sodium chloride, that is, about one fifth of that contained in sea water.

The ordinary eruption occurs usually five times in a day and night. During the time of repose, we see only a small quantity of steam rising from the mouth. As the time of the eruption approaches, a rumbling sound is heard underneath. Boiling water appears just inside the mouth. It soon retires and again appears. This state is continued for about three quarters of an hour. Next a small quantity

of hot water flows out intermittently. This is followed by an intermittent stream of moderate quantity with a longer period. The activity soon attains its maximum. A torrent of hot water gradually increasing in force, is torn into a violent splash and projected with great velocity by the steam, which gradually increases with the diminishing water. When the roaring sound of the steam reaches its maximum, the water almost disappears. The steam now diminishes and is soon followed by a second gush of water. When these discharges of the water and steam have been repeated five or six times, activity ends with the last discharge of steam, which gradually subsides into an amount as inconsiderable as at the beginning. It takes above two hours from the beginning to the last stage of the eruption. The time of repose is a little less than three hours on the average. These regular recurrences are often interrupted by an abnormal outburst called *nagawaki*, at which the water and the steam come out incessantly for above twelve hours, after which as a rule a long repose follows. In years most noticeable for this anomaly, it has occurred almost monthly, whereas in the last few years only two or three times.

II. ARRANGEMENTS FOR OBSERVATIONS.

To make detailed observations of the general manner of eruptions, the following arrangements were used.



A pendulum was made of a brass rod, at the lower end of which a lead ball was fixed (3 cm in diameter), and vertically suspended by a short horizontal axis fixed to the rod and pivoted to a catch at the end of a large wooden beam laid horizontally over the principal orifice. The pendulum hung nearly vertically, the lead ball facing closely to the mouth. To the upper end of the rod was attached a string, which passed horizontally to a pulley of the recording instrument. The string after passing over the pulley was attached to a suitable weight. The whole system was so adjusted that the pendulum hung vertically under the balancing action of its own weight and the tension of the string going to the recorder. When the eruption begins, the pendulum is deflected by the pressure of the water and steam. The vertical part of the string below the pulley conveys a pen, which is guided as in the limnimeter⁽¹⁾ used by one of us for recording the level change of artesian wells. The motion of the pen is recorded on a cylinder rotating about a vertical axis. From the records obtained, we can easily distinguish the water and steam-pressure from each other. The part of the record representing the water pressure is much disturbed by zigzags.

Since it was, however, desirable to record the water and the steam separately, the pendulum was transferred to a place in front of the orifice, where all the water ejected flows through a narrow canal to a tank. The whole system was shielded off from the impulsive action of the splash and the steam by a screen of wooden planks. The records thus obtained were completely free from steam pressure.

To record the pressure of the steam only, was a matter of considerable difficulty. Just before the orifice, the steam pressure was tolerably strong; but, there, it was impossible to separate the steam pressure from that of the water. Where the ball of the pendulum did not receive any pressure from the splash of the water, the steam pressure was not strong enough to cause any sensible deflection of the pendulum, so that the arrangement failed to give any

1) K. Honda, Publications of the Imp. Earthq. Inv. Comm., No. 18, p. 73.

satisfactory result. The aspiration method was also tried, but it failed to produce sensible diminution of the pressure in our recording apparatus. We, at last, adopted the following arrangement, which was essentially nothing more than an air-thermograph. A hollow cylinder or a bulb of iron sheet (radius=2 cm, length=9 cm) was introduced into a side orifice (a), where the water flows out slowly, and where it was possible to find a position such that the bulb was exposed to the heating actions of the steam only. To avoid too rapid expansion and contraction of the enclosed air, the bulb was covered with two layers of cloth. Since this orifice is a small branch of the principal orifice, and the manner of the eruption quite similar for both mouths, the side orifice may be considered as representing the mode of eruption in the principal one on a reduced scale. The bulb was connected by a fine copper capillary tube (diameter=2 mm.) to one of the arms of an U-tube containing mercury. In another arm of the tube, a float carrying a light vertical pen-holder was introduced. The motion of the float caused by the expansion and contraction of the air inside the bulb, was recorded on a vertical drum by the pen, guided as in the case of the limnimeter.

For the statistical investigations, a simple apparatus which might continuously record the exact time of eruption and also, if possible, the general manner of each eruption was desirable. For this purpose, a mercury tide gauge constructed after Mr. S. Nakamura's design¹⁾ served very well. The lead pipe of the instrument was inserted in the neck of the geyser. At the beginning of activity, the instrument records the periodic level-change of the head of water inside the orifice. When the velocity of the water increases, it records the kinetic pressure of the ejected water. The steam pressure does not display itself on the records. The instrument has been working satisfactorily since the end of March, 1904.

For the determination of the temperature, a maximum thermometer which was graduated up to 150°C, was used.

1) S. Nakamura, Proc. of Tokyo Math.-Phys. Soc., Vol. I, p. 123.

III. RESULTS OF OBSERVATIONS.

1. *Ordinary Eruption.*

a) Flow of water and steam. Fig. 1.

To record the initial stage of eruption, the lead ball of the pendulum was lowered as near as possible to the bed of the canal just outside the mouth, and the small initial quantity of water was compelled to flow entirely through a narrow aperture cut in the edge of a wooden board fixed to the bed close to the mouth. The ball hung just outside the aperture.

Referring to Fig. 1, we see that there exist three distinct series of intermittences. The first series which appears as an introduction to the display, consists of a small quantity of water with an average period of $1^m 40^s$. After this intermittence has been repeated a score of times, the second series follows. A moderate quantity of water comes out three or four times with a mean interval of 6 minutes. The water increases in quantity and force, till at last the third or principal series sets in. On the first outburst of the third series, we see always the superposition of the last one of the second series. The third series is to be distinguished from the previous series by both its violence and the quantity of the water and steam put out. Besides, the roaring sound of the steam is a remarkable characteristic of this series. The sequence of the water and steam occurs with a mean period of about 11 minutes, and is repeated usually five or six times, not rarely four or seven times.

The pendulum was actuated by the impulsive force of the water and steam; the diagram shows a greatest excursion somewhat later than the actual maximum of the water. In this stage, the velocity of the steam is gradually increasing. When the water decreases to an inconsiderable spray and the steam predominates, the pendulum draws back. The disappearance of zigzags in the curve shows the prevalence of the steam.

b) Flow of water only. Figs. 2 and 3.

The records are generally similar to those given in Fig. 1, except that in this case, the impulsive pressure of the steam and splash is almost entirely eliminated. In these diagrams, we also see the superposition of the second series at the beginning of the third one. It will be observed that the last one of the third series is often distinguished by the small quantity and the weak force of the water.

c) *Flow of steam only. Figs. 4 and 5.*

In these diagrams, the zero line falls abruptly as soon as the cloth of the bulb is wetted by the condensed steam; this is due to the cooling caused by the evaporation. The ordinate of the curve may be considered as indicating in some measure the velocity of the steam at any instant and hence the area enclosed by this curve and the zero line is a rough measure of the quantity of the steam expelled. In subsequent experiments, it was found better to take the envelope off the bulb, whereby the falling of the zero line is avoided.

When two corresponding diagrams, Figs 2 and 4, or 3 and 5 are placed one upon another so as to bring their abscissae into coincidence, the recurrence of the alternate ejections of the water and steam can clearly be seen.

d) *Level-change during the time of repose. Figs. 6 and 7.*

The end of the lead pipe of the tide-gauge was inserted in the neck of the geyser as deep as possible. It was estimated that the end was only a half meter below the mouth. Since the neck is crooked in a very irregular manner, further attempt to insert the tube deeper than this failed. The record was continuously taken from the end of one eruption to the beginning of the next one.

The diagram obtained reveals to us a remarkable fact that within about 40 to 50 minutes after the end of an eruption, the head of hot water appears within a half meter below the mouth. The head seems to oscillate about its position of equilibrium for about one and a half to two hours, till the next activity begins. This interval may be considered as the time of preparation for the next eruption.

e) *Time of occurrence. Figs. 8, 9 and 10.*

The end of the lead pipe was drawn up to just inside the mouth. The clockwork gives one revolution every 24 hours. The records have been taken continuously from April, 1904, up to the present. From the statistical investigation of these records, we may infer the following facts:—

i) From April, 1904, to March, 1905, the mean period of the eruption was very nearly $24/5$ hours. In May, 1905, there occurred an abnormal decrease of the activity of the geyser and since August of the same year, the activity has decreased to about four times per day.

ii) If the times of occurrences be plotted on a diagram, the successive days as abscissae and the hours of the day as ordinates, we obtain a set of five points per day. Connecting corresponding points, five broken lines are formed. These lines show a striking parallelism with the inverted curve representing the variation of the mean atmospheric pressure for successive days. The high pressure corresponds almost without exception to the short period and the low pressure to the long period.

iii) The sum of the daily intermittence of water and steam given out, taken for the five daily eruptions, is generally abundant on the days in which low pressure prevails. The eruptions in which the alternations of water and steam occur more than eight times, fall in usually with approaching low pressure.

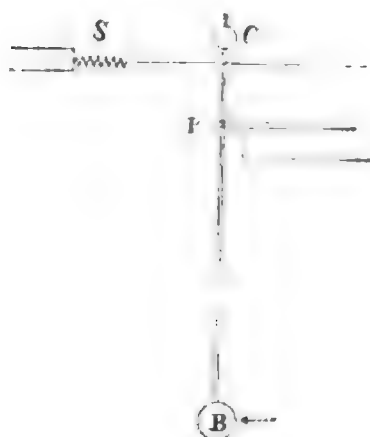
f) Temperature of the hot water during eruptions.

A maximum thermometer was placed about 1.5 m inside the orifice and the temperature has been read daily during about a half year. It was found that the temperature at this depth is almost invariably 103° - 104° C. At the orifice, however, it was about 100° C, indicating a rapid cooling of the hot water. It may, therefore, easily be conjectured how hot the underground water would be at a depth of some ten meters.

g) Velocities of the water and the steam.

To determine the velocities of the water and the steam, the pendulum arrangement was modified in the following way. The pendulum bob was replaced by a larger brass one B, and the center of mass of the

pendulum was brought to the axis of rotation P by using a counterweight C, as shown in the annexed figure. From the upper part of the pendulum rod, two strings were stretched in opposite directions,



one of which passed to the recording apparatus, while another one was stretched by a spring s fixed to a rigid support. The weight of the recording apparatus was so adjusted that the rod hung vertically, when it was acted upon by no pressure. When the pendulum was set to work in a proper stage of an eruption, the pressure due to the water and the steam

could separately be observed. After the record has been taken in the usual manner, a series of known weights—30, 50, 80, 100, 200, and 300 grams—were successively applied to the pan hanging under the recording pen, and the corresponding deflections of the rod were recorded on the cylinder. From these observations, we could calculate the amount of the pressure exerted by the water and the steam upon the brass ball.

The total pressure exerted by a fluid stream upon a sphere is known to be approximately equal to one half of that upon a circular disc of the same diameter. Hence

$$p = \frac{\pi r^2 \rho v^2}{2}, \quad \text{or} \quad v^2 = \frac{2p}{\pi r^2 \rho},$$

where p is the pressure, r the radius of the ball, ρ the density and v the velocity of the water or the steam.

For the water, the maximum velocity was calculated to vary from 1.5 to 2.0 m per sec.

For the steam, the velocity was found to vary from 18 to 24 m per sec., as given in the following table:

No. of Intermittence	Velocity
1	24 m/sec
2	25—24
3	22—18
4	24—23
5	22—18
6	22—18

In the above calculation, we took for the value of ρ , the density of saturated vapour under atmospheric pressure.

h) Quantities of water and steam.

Since the quantity of the water and the steam in each eruption differs considerably for different eruptions, it was sufficient to get a rough estimation of the amount. Again, to make an exact measurement of the total quantity of the water or the steam is almost hopeless, in the present condition of the orifice, as it is branched into several mouths; some of these are hidden underground, whence the hot water is distributed by a number of separate conduits.

The direct method for the quantity of the water was to measure the quantity supplied to a number of tanks and to estimate the total from the section of the conduits. The tanks chosen for this purpose were those of Kyūkikwan and of Sagamiya. The results are:

Kyūkikwan	11 ^h	p.m., April 1, '04.	3.38 m ³
Sagamiya	11 ^h	a.m., „ 2, „	1.28.

Since the numbers of the conduits for the exposed orifices A, a, a' are 21, 2, 3 respectively, the total quantity of the water will approximately be $1.28 \times 26 \text{ m}^3 = 33.2 \text{ m}^3$ or 184 *koku*. It was also estimated that the total quantity of the water which flows out from the hidden orifice, is $3 \times 3.38 = 10.1 \text{ m}^3$ or 56.3 *koku*. Hence the whole discharge of one eruption will approximately be 45 m^3 or 250 *koku*. This number is a little greater than that obtained by Dr. Tawara, and nearly coincides with that given by J. Tsuyuki, a resident in Atami.

The rough estimation of the steam was carried out in the following way. Let the quantity of the steam be denoted by Q , we have

$$Q = \int Sv \rho dt,$$

where Sv is the flux of the steam. If V be the ordinate of the steam diagram, we may put

$$v = kV,$$

$$\therefore Q = S \rho k \int V dt.$$

In our case, k was found to be 500 and S was estimated to be 300 cm^2 . Hence

$$Q = 121 \int V dt.$$

For an eruption, we found $\int V dt = 6500$, and therefore

$$Q = 800 \text{ kg.} = 213 \text{ kwan}$$

These numbers for the water and the steam must be considered as giving the orders of magnitudes of these quantities.

2. Abnormal Eruption, the Nagawaki.

Figs. 11 and 12.

The record of *nagawaki*, kept at Kyūikikwan is given below:

- 1894: Jan. 6; Feb. 22, 7^h p.m.—23, 11^h a.m.; March 30, 4^h p.m.—31, 6^h30^m a.m.; April 30, 6^h a.m.—2^h p.m.; June 7, 5^h a.m.—5^h p.m.; Aug. 20, 4^h p.m.—21, 6^h a.m.; Sept. 27; Nov. 17, 4^h a.m.—4^h p.m.; Dec. 28, 8^h a.m.—8^h p.m.
- 1895: Feb. 18, 4^h p.m.—19, 5^h a.m.; April 9, 8^h a.m.—5^h p.m.; June 12, 4^h p.m.—13, 6^h 30 a.m.; Aug. 14.

After this date, the record is missing till 1903.

1903: Sept. 8^h p.m.; Dec. 29, 3^h p.m.

1904: None.

The first *nagawaki* recorded by our arrangement began at 4^h30^m a.m. on Jan. 14, 1905, from the third series of the ordinary eruption. During two or three days before the *nagawaki*, the period of the

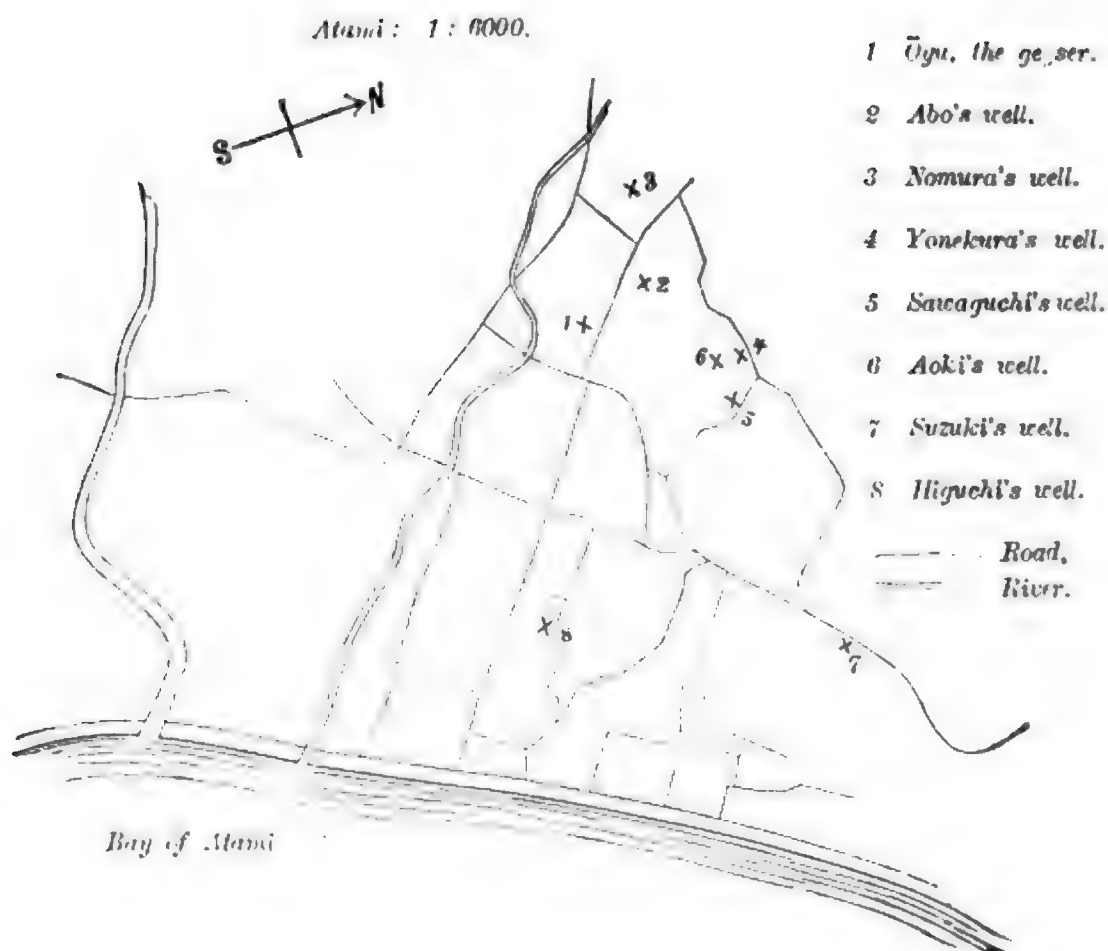
successive eruptions seems to have been slightly diminished, but in such a degree that may be found not seldom in our records, without leading to either *nagawaki* or anything extraordinary. The *nagawaki* began, as it were, almost suddenly in the midst of an ordinary eruption. As given in Fig. 11, the flow of the water continued without interruption, gradually decreasing in quantity and mixed up with the steam. At 7^h40^m p.m., it came to a sudden repose; at 2^h40^m a.m. on 15th, an intermittent flow of hot water resembling the second series of an ordinary eruption began and continued for about three hours. After a repose of four hours, ordinary eruption at last set in, but with the period remarkably shortened and the general activity strikingly reduced. The number of eruptions per day was ten, a remarkable contrast to the ordinary frequency of five per day. The frequency decreased afterward very slowly with the time (Fig. 12), and recovered its original value after the lapse of about a month.

The second *nagawaki*, which occurred on May 27, 4^h 30^m a.m.—28, 6^h 20^m a.m., '05, was quite similar to the previous one in its general aspects, though it took place in conjunction with an extraordinary decrease of the general activity. The third *nagawaki* occurred on Dec. 13, 6^h p.m.—14, 9^h 40^m a.m., '05, and the fourth on March 6, 6^h 40^m a.m.—7, 2^h a.m., '06. They are quite similar in the general aspects to the one above referred to. It is an interesting coincidence that these *nagawakis* began at the same phase of the ordinary eruption, and that a center of low atmospheric pressure was approaching from the Pacific in each case.

3. *Extraordinary Decrease of Activity.*

Figs. 13 and 14.

During the course of the last few years, several wells have been bored in this district. Many of them give a moderate quantity of hot water only by pumping. In 1905, the number of the wells has been greatly increased, amounting to about twenty in all. Sawaguchi's well bored on March 27, '05, burst out with great force, continuously



throwing up a column of steam and hot water about 8 m high. On May 22, another, Yonekura's, of a much greater activity was opened within a few hundred meters from the geyser, giving out hot water at a rate of about 310 cubic meters per day. Two days afterwards, still another, Higuchi's, of not much less activity was bored. After the boring of the Sawaguchi's, a slight decrease in the frequency of the geyser was observed; on May 20, it was reduced to 4.4 times per day, though the force of each eruption presented no appreciable change. After the boring of the other two, the frequency of the geyser remarkably decreased; it was 3.6 on May 26. Moreover, the first and the second series of each eruption became considerably longer than usual and the principal series was lessened in force. After the *nagawaki* which occurred on May 27, the number of eruptions per day was temporarily increased to 6, though the quantity of the hot water

was rather decreased. On June 5, the frequency again fell to 3.6 and on June 11 to only 3.2; the first and the second series were prolonged to three and a half hours, while the principal series was reduced to only three weak eruptions. The consequent decrease in the quantity of hot water caused trouble to several bath-houses supplied by the geyser, and the above three wells which must have been the probable cause of the decrease, were all stopped—Yonekura's on June 12, Sawaguchi's on the next day and Higuchi's on July 12. Immediately after the stoppage of the first two wells, the frequency of the geyser increased to 4 and moreover the preliminary series of each eruption was shortened and the principal eruption gradually tended to regain its original force. After stopping Higuchi's, the frequency gradually increased and attained 4.5 in August, which was still a little short of the original value. Since then, the frequency has gradually decreased to 4 and remained nearly constant up to the present, though it was temporarily disturbed by two *nagawakis*. As to the mode of each eruption, it has quite recovered its original force. It is to be remarked that still new wells remain open, Aoki's, which are near the geyser and give a moderate quantity of hot water.

The stoppage of wells was a matter of no small difficulty. The sight witnessed by us during the stopping of Yonekura's well may be worth recording. The well was about 25m deep and threw up a column of hot water mixed with steam about 8 m high, from an iron pipe of 4 inches diameter. Cylinders of sheet iron filled with sand and pebbles which were intended to stop the well, were violently thrown up in the air when put in the orifice. An iron rod of about 10 kg weight thrown into the mouth was held by the water near the mouth, neither falling nor rising. Next, an iron pipe of 2 inches diameter and of about 6 m length, was filled with sand and forced into the orifice. Though the quantity of the water and steam was considerably lessened by this pipe, the upward pressure still overcame the weight of the pipe and when the pipe was released, it was thrown up into the air about one meter high. Next a similar pipe filled with

iron bolts and sand was applied. This pipe fell freely down the well. Immediately, the quantity of water was greatly reduced and a number of pieces of tuff imbedded with small crystals of iron-pyrites, was pelted out with the jet of steam and scattered within several meters from the spct. Then another iron pipe was thrown into the hole and cold water was poured down, which completely stopped the activity.

From the fact that the iron bar above described was held in equilibrium by the pressure of the water jet, we may roughly estimate the velocity and the mean density of the splash at the orifice. If w be the weight and S the sectional area of the rod, and if ρ be the mean density and v the velocity of the jet, we have

$$w = Spv^2$$

Again, if R be the radius of the orifice and Q the quantity of water given out per second,

$$\pi R^2 v \rho = Q$$

By our previous measurement, $Q = 0.0036$ cubic meter per sec. The result of our evaluation is thus

$$v = 12 \text{ m/sec}; \quad \rho = 0.73,$$

i.e., the jet of water fills up about 7/10 of the area of the orifice. The power of the jet calculated from these data is about 3.5 H.P.

4. *Level Change and Temperature of Artesian Wells.* Figs. 15 and 16.

Level-changes of two wells near the geyser were recorded by means of Honda's limnimeter. Nomura's well, which is within 200 m of the geyser and 25 m above the sea level, shows a regular up and down motion of about 10 cm, five times per day (Fig. 15) corresponding to the eruption and repose of the neighbouring geyser. When the geyser is at the height of its activity, the level of the well is at its maximum. The slow rising of the mean level is partly due to rain. Effects of the tidal and the atmospheric pressure are also recognizable, but not very remarkable. The temperature of the water in this well is 50°-60°C.

In Suzuki's well, situated more remote from the geyser than the

Nomura's and nearer to the sea, the effect of the geyser is not observed, but the level rises and falls with the tide (Fig. 16). The record shows peculiar zigzags indicating that the surface of the water is continuously disturbed by the boiling. If the water be pumped out a little at first, it continues to flow eruptively for a while, till a definite quantity is reached and then follows repose. If the pump be actuated again after a few hours, a nearly equal quantity of boiling water flows out in a similar way. But, if pumped earlier, a small quantity may be drawn out only after hard pumping. The level of this well is about 11 m below the ground and 22 m above the sea level. On one occasion, the temperature of the water in the well at different depths was measured with a maximum thermometer and found to be remarkably high. The results are given in the following table:—

17.6 m	6.6 m	103°C.	115°C.
26.6	15.6	123°	128°
32.1	21.1	139°	135°
35.7	24.7	146°	138°
44.9	33.9	140°	147°
54.0	43.0	142°	152°

The first and the second column denote the depths measured from the surfaces of the earth and the water respectively; the third column is the actual temperature corresponding to each depth; and the last is the corresponding boiling point of water under pressure, calculated from the Regnault's results. From the above table, we see that the temperature of the water rapidly increases almost proportionally with the depth up to about 20 m from the surface of the water; then the rate of the increase becomes abruptly small. This shows that at about 20 m below the surface of the water, there is a layer or a space between layers in which highly heated water is continuously flowing. At these depths, the actual temperature is a few degrees higher than the corresponding boiling points under pressure, so that the boiling is continuously going on, as shown by the limnimeter set up in the well.

Here it is to be noticed that the rise of the boiling point due to the dissolved substances is at most one degree.

Abo's well which is situated midway between the geyser and Yonekura's well, is about 33 m deep and gives out hot water by pumping. The results of the temperature measurement at different depths, made by a maximum thermometer, are as follows:

At the water surface	62.0 C.
23.0 m below,	95.5
28.5 "	98.3
29.7 "	104.3
31.0 "	118.2

From the results in these two wells, it is evident that in the district of Atami, there exist layers with very high temperature near the surface.

IV. EXPLANATION OF THE PHENOMENA.

Existing theories are not sufficient to explain the exact manner of the eruption of the geyser of Atami. Wiedemann's model though plausible in many respects, fails when applied to this geyser, in which water and steam are alternately projected several times in succession. We sought, therefore, for other alternatives and constructed several models for experiments.

First, we conceived two subterranean cavities (*A* and *B*) connected in series, as shown in the annexed figure and supposed *B* to begin the

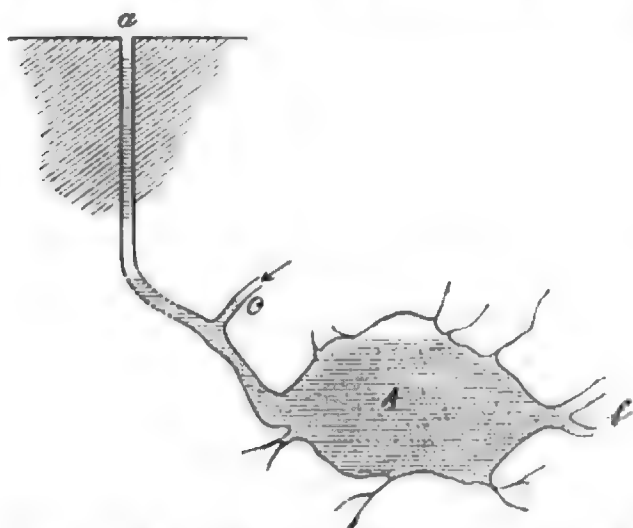


eruption earlier than *A*, by the underground heat. The model constructed according to this supposition worked almost satisfactorily, except that the mode of intermittence in the principal series of the eruption was not quite similar to the actual geyser; for, in this model, the steam predomi-

nated toward the end of each eruption, instead of showing a regular alternative intermittence of steam and water as in the actual case.

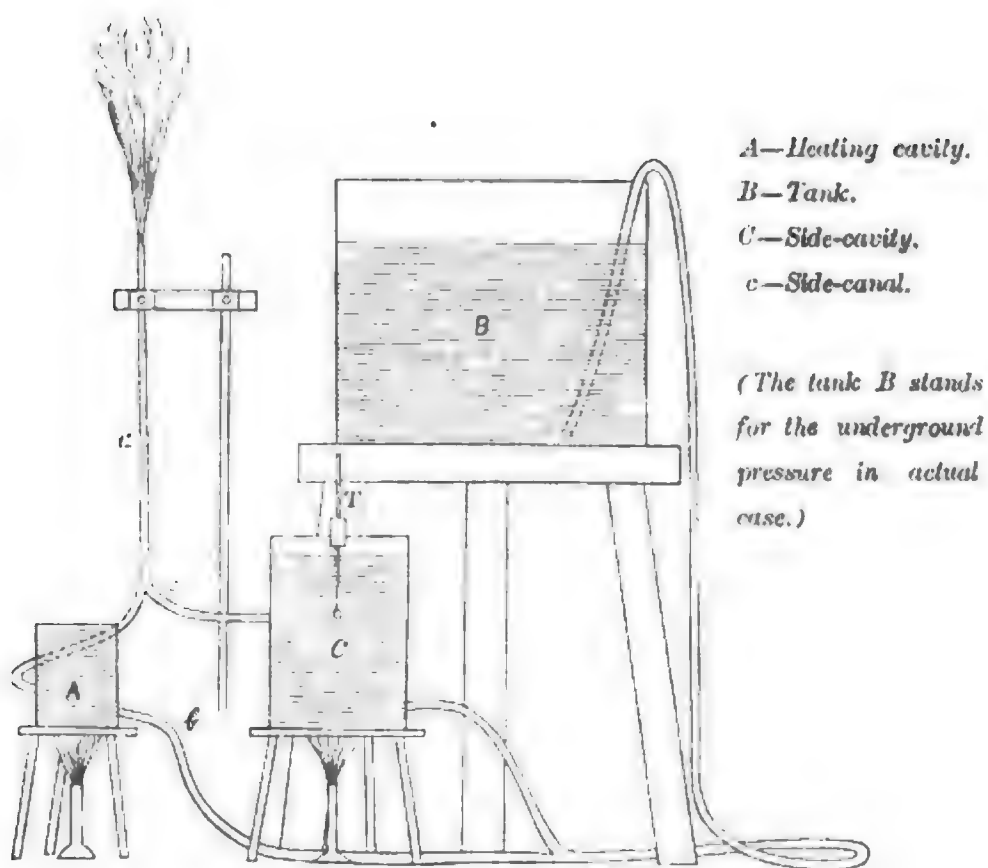
After a sequence of modifications and experiments under various conditions, we arrived at last at the following theory which seems for the present to be sufficient to explain the phenomena of the geyser in question :—

Referring to the figure, *A* is a cavity lying at a considerable depth; *a* is the vertical pipe and *b* a canal which supplies the water to *A*. We conceive a side-caual *c* intermediate between *A* and *a*, which leads to a second cavity *C*, not shown in the figure. The temperature of the water in *a* and *c* is supposed to be lower than the corresponding



boiling point. Water in *A* is heated by the wall of the cavity, the temperature of which is supposed to be decidedly higher than the boiling point at that depth. The source of the heat is probably to be attributed to the hot water and steam running through numerous

veins and canals extending beneath the district. When the tension of the vapour in the cavity attains its critical value, the water is ejected and then the steam follows. When a certain amount of the steam is given off, the pressure in the neck is reduced to such a degree that the water flows in from the side-canal and stops the eruption momentarily. Soon, the downward pressure of the water column is overcome by the tension of the vapour and the second gush follows. These eruptions are repeated several times, till the vapour pressure is so reduced as to admit the comparatively cold water from the feed-canal *b* and also from *c*. Thus the activity is quenched for a while till the next eruption begins.



A model constructed according to this view worked satisfactorily. Referring to the figure, *A* is the working cavity, *c* the side-canal fed by the second cavity *C* larger than *A*. *B* is the large tank supplying *A* and *C*; *a* is a glass tube representing the vertical pipe of the geyser. These are all connected by cauchouc tubings as shown in the figure. Both *A* and *C* are made of brass, thickly covered with asbestos to prevent cooling, and moreover, are provided with glass gauges showing the water levels inside. The cavities filled with water are heated by proper Bunsen burners, care being taken to keep the temperature of the water in *C* somewhat below the boiling point—the temperature being read by the inserted thermometer *T*. We give below the dimensions of the principal parts of our model:—

Capacity of *A*: Height = 13.0 cm; Diameter = 9 cm.

„ „ *C*: „ = 18.5 cm; „ = 15 cm.

Height of the orifice above the bottom of *A* = 1 m.

Internal diameter of the vertical pipe = 5 mm.

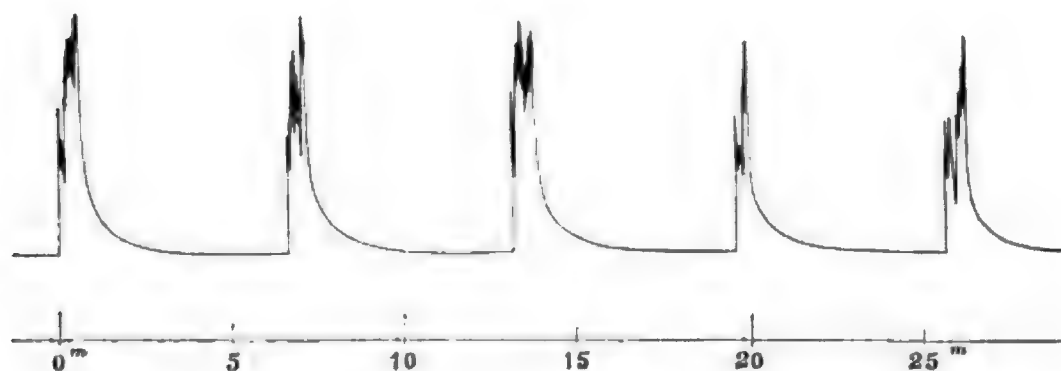
Diameter of the orifice = 2.5 mm.

„ „ „ tube $b = 7$ mm.

„ „ „ „ $c = 5$ mm.

The period of the eruption depends on the heating of the cavity A , increased heating shortening it. The number of the intermittences increases with the temperature of the water in C . In our experiments, the mean period of the eruption was 6.5 minutes and when the temperature in C was 95°C , the number of intermittences in each eruption was 3 to 4.

In this way, the manner of the eruption was imitated even in its details. The figure here given is one of the records of the eruption



of our model, obtained by the air-thermograph already mentioned. The preliminary series of the eruption was not recorded by this arrangement, in which the air-bulb was placed somewhat high above the orifice.

The phenomena of *nagawaki* may be explained partly by the supposition that the underground temperature is raised above its normal value and so the temperature of the cavity C becomes higher than the ordinary value. If the temperature of the cavity C in our model be raised to a certain value, the eruption corresponding to *nagawaki* begins. It resembles the actual one even in some details. The cause of this occasional change of the temperature is probably the change of the subterranean volcanic activity, which keeps the underground temperature in this district considerably above the boiling point of water.

The fact that the frequency of the eruptions immediately after *nagawaki*, is nearly doubled, may partly be explained, if we consider that the temperature of the heating cavity is raised during the course of the *nagawaki* by the incessant flowing of superheated water. It may be added as a very suggestive fact that if in our model, a quantity of air be blown into the heating cavity, the frequency of the eruption increases remarkably at first and then gradually decreases with the gradual expulsion of the air by the successive eruptions; even the weakness of the activity in the actual case is imitated with great faithfulness. During a few hours after *nagawaki*, the cavity as well as the canals leading to the orifice remain drained out, so that it is possible that air or other gases may enter into the cavity and cause the increased frequency of the eruption.

It is a fact of common observation that the temperature of some ordinary hot springs rises with the low atmospheric pressure. This is undoubtedly due to the increase of the flow caused by the enhanced circulation due to the reduction of the pressure. If in the supposed heating cavity of the geyser, the interchange of the water due to the slow circulation through numerous veins and fissures be accelerated by some cause, the time required for the sufficient heating for the eruption must necessarily be prolonged. This consideration seems to explain the influence of the atmospheric pressure on the period of the eruption above mentioned. Again, the probable influence of the well-boring on the geyser, may be explained on the same basis. The wells may increase the circulation of the underground water in the vicinity and result in the retardation of the eruption of the geyser in a similar manner. Moreover, it is quite natural that the hot water would find its easier vent through a new passage opened with less resistance, at the expense of the quantity originally ejected by the old one alone. The prolongation of the first and second series of the eruption, suggests the slowness with which the pressure in the heating cavity approaches the critical value. Careful investigation of the change in the wells, leads us to the strong belief that the striking

coincidence of the well-boring and the extraordinary decrease of the change in the geyser, is a necessary and not an accidental one. If the frequency of the eruption does not yet quite attain its former value, long after the stopping of the wells, we need not wonder at all, since some irreversible change in the subterranean mechanism might have happened during the period of the disturbance.

It should be noticed that almost simultaneously with the beginning of the abnormal decrease of the activity, severe shocks of earthquake were felt in the Island of Ōsima, an active volcano situated in front of Sagami Bay, about 27.5 miles from Atami. On this account, it was generally believed that the decrease was the consequence of some change of the subterranean activity associated with the earthquake. The belief seems to have its origin in the tradition that the occurrence of *nagawaki* has some relation to the activity of Ōsima. But, judging from the manner of the change of the geyser accompanying the boring and stopping of the wells, we are inclined to believe that the principal cause of the disturbance is to be attributed to the well-boring.

The question naturally arises as to the actual source of the immense quantity of the hot water poured out daily by this geyser. It seems, according to the accepted view of the modern geologists, that the water condensed from the superheated steam coming from the very depth of the earth's crust forms a considerable part of the mineral water of such a hot spring. Accepting this as a partial explanation, we feel inclined to trace the greater part of the hot water ejected by this geyser to the underground water circulating at a comparatively small depth heated by the extraordinary heat under the district. The presence of the sea-water constituents in the water of the geyser is probably due to the sea-water penetrating through several fissures in the neighbouring bay, which bears strong geological evidence to having once been the crater of an volcano.

In conclusion, we wish to express our best thanks to Mr. S. Kusumi, the apotheker to Kyūrikwan, to whom we are very much indebted for his zealous assistance during the course of our observations.

General View of Island.
 Being about 100 yards in length and 50 in width.



Cliffside in Japan.

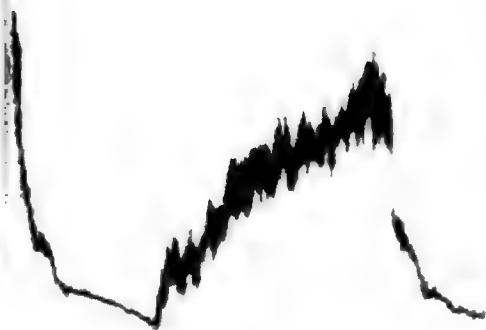
A small stream flows down the cliffside, and the water is very clear.



Japan in 1900, showing

the great stone wall and the old castle.

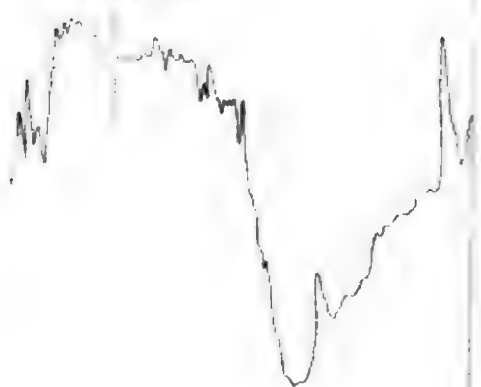




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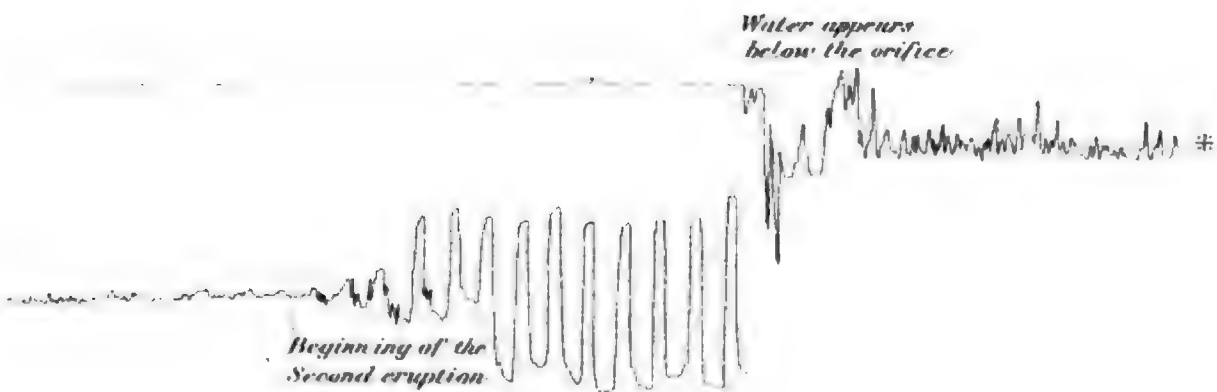
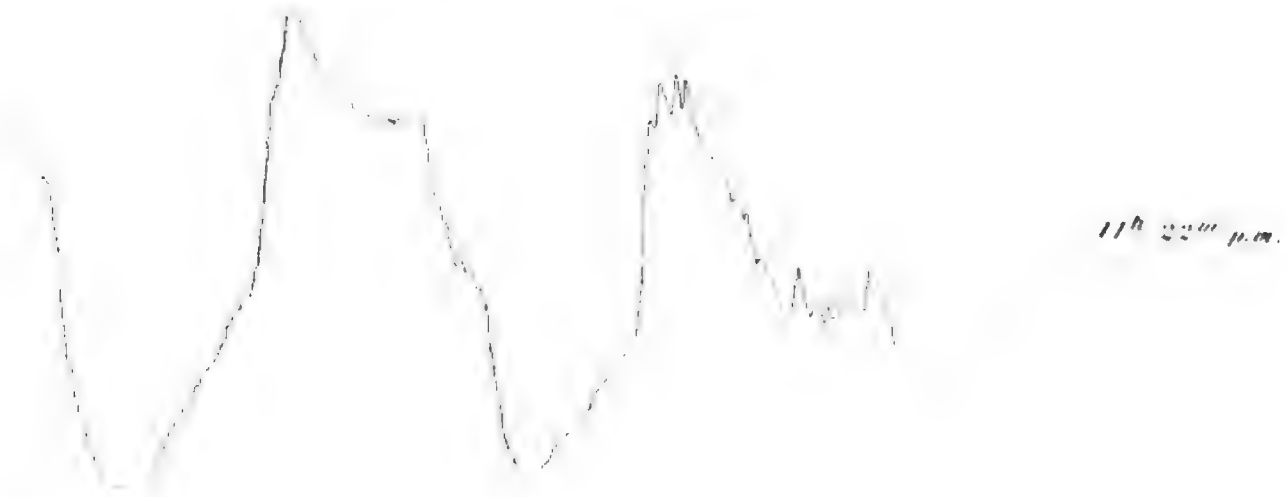
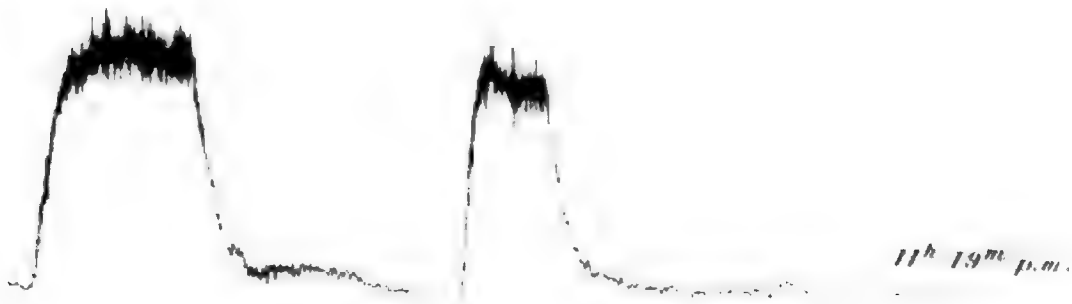
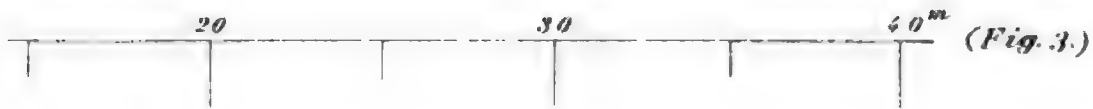


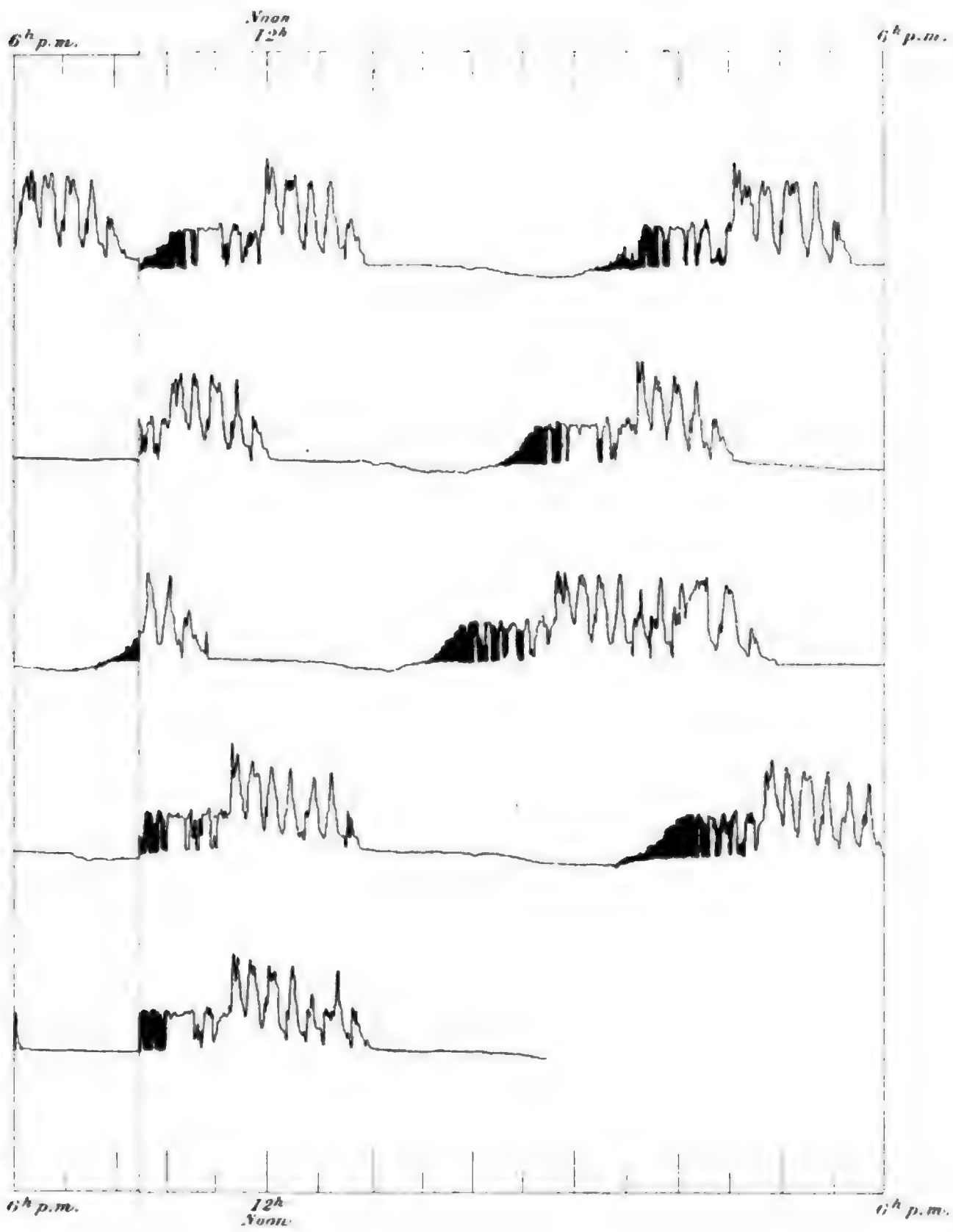
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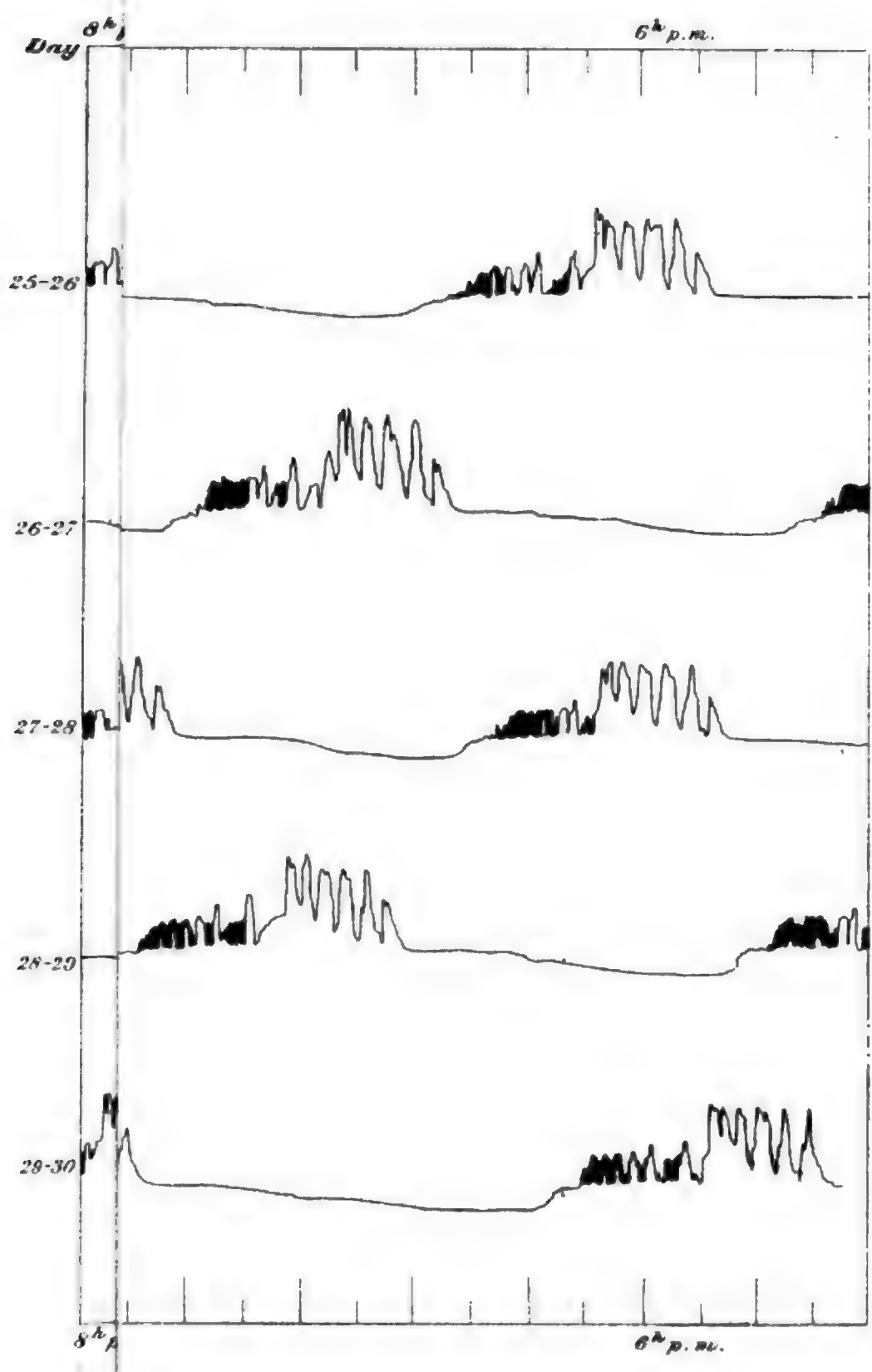


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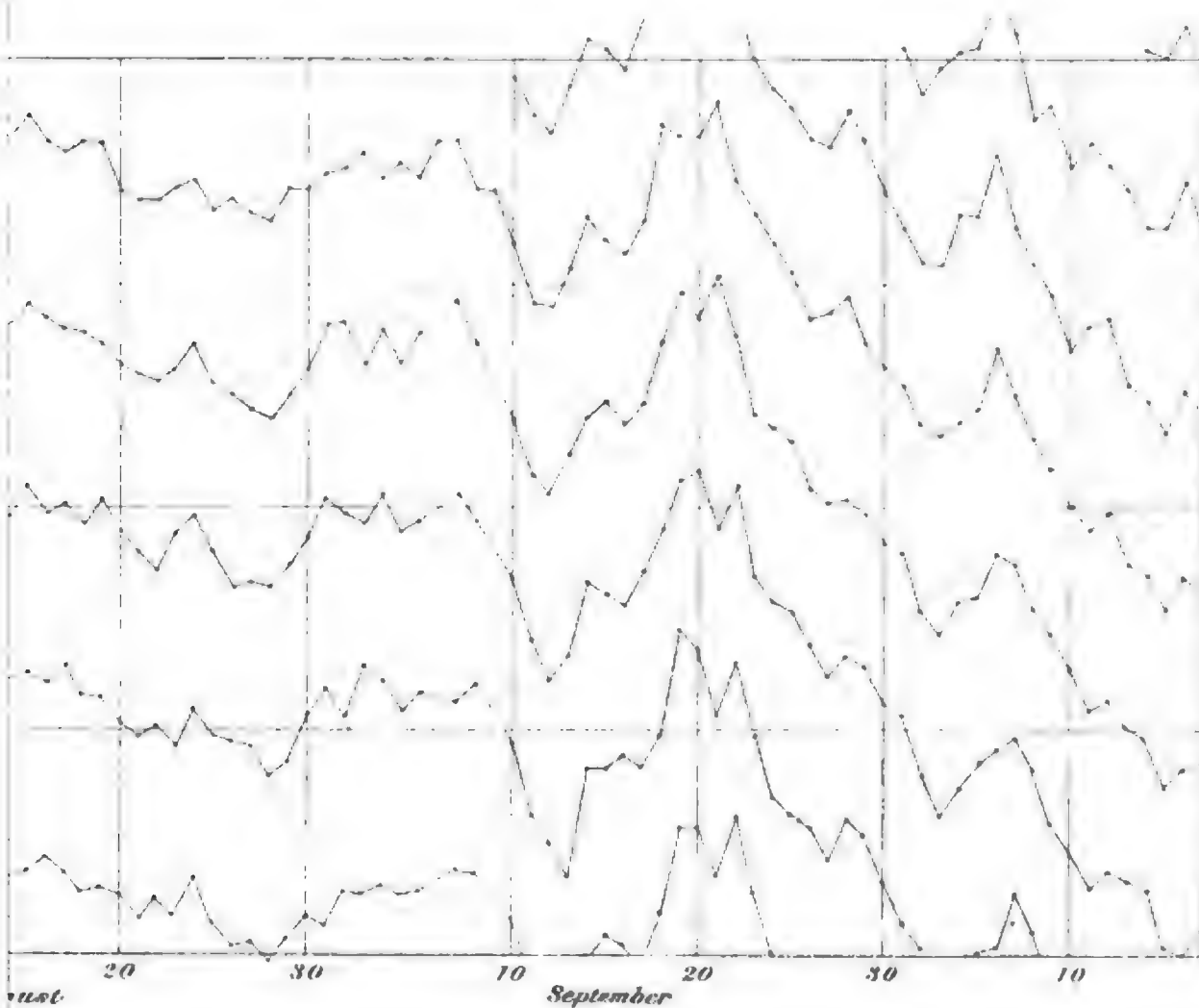
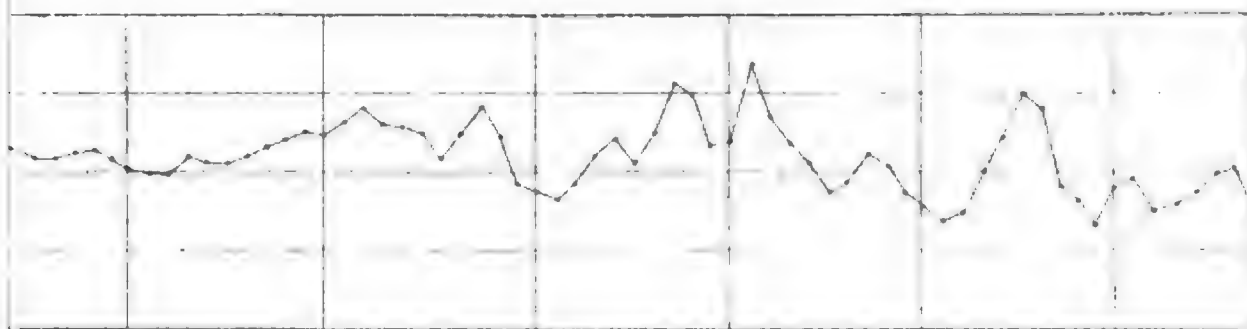
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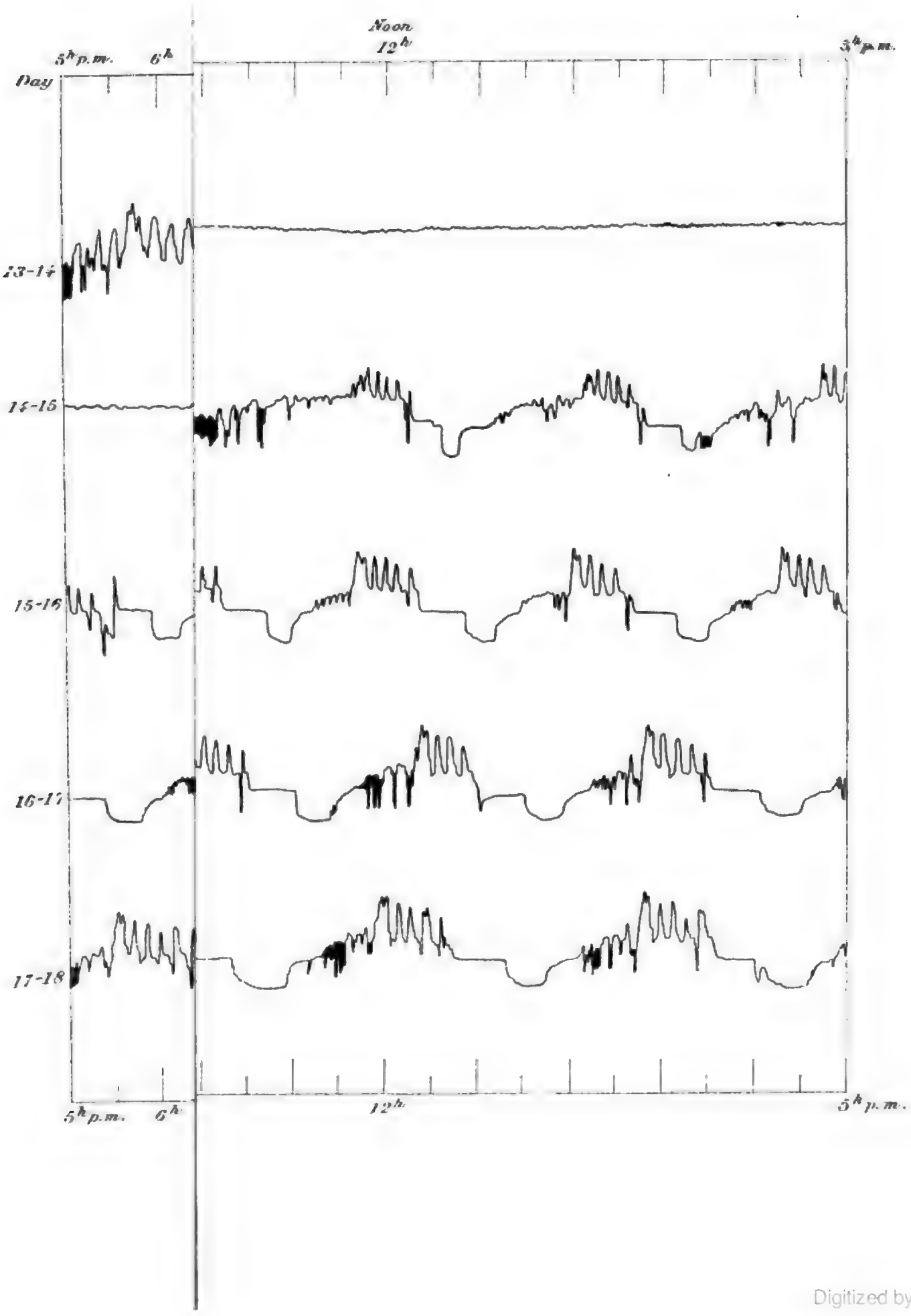


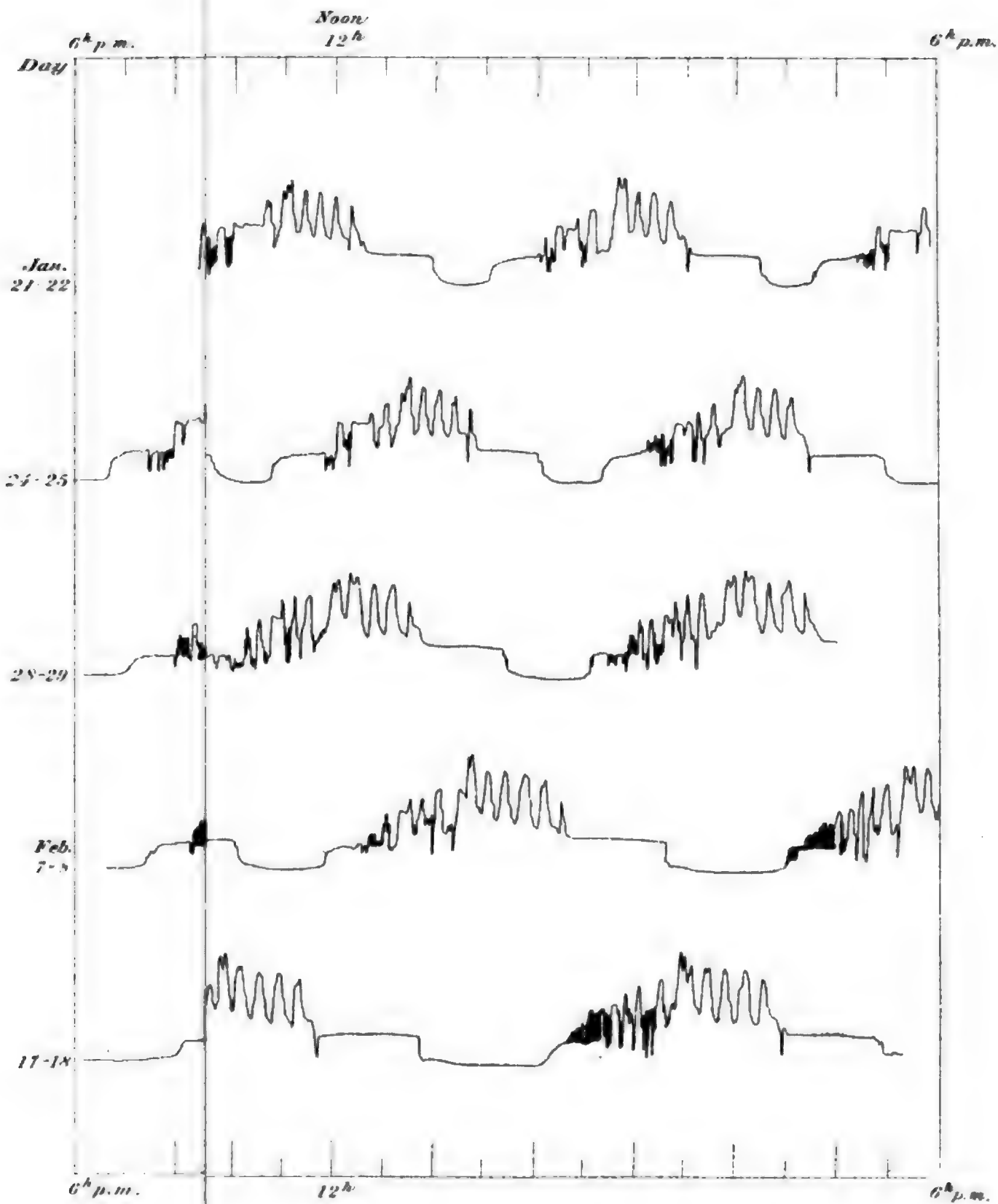


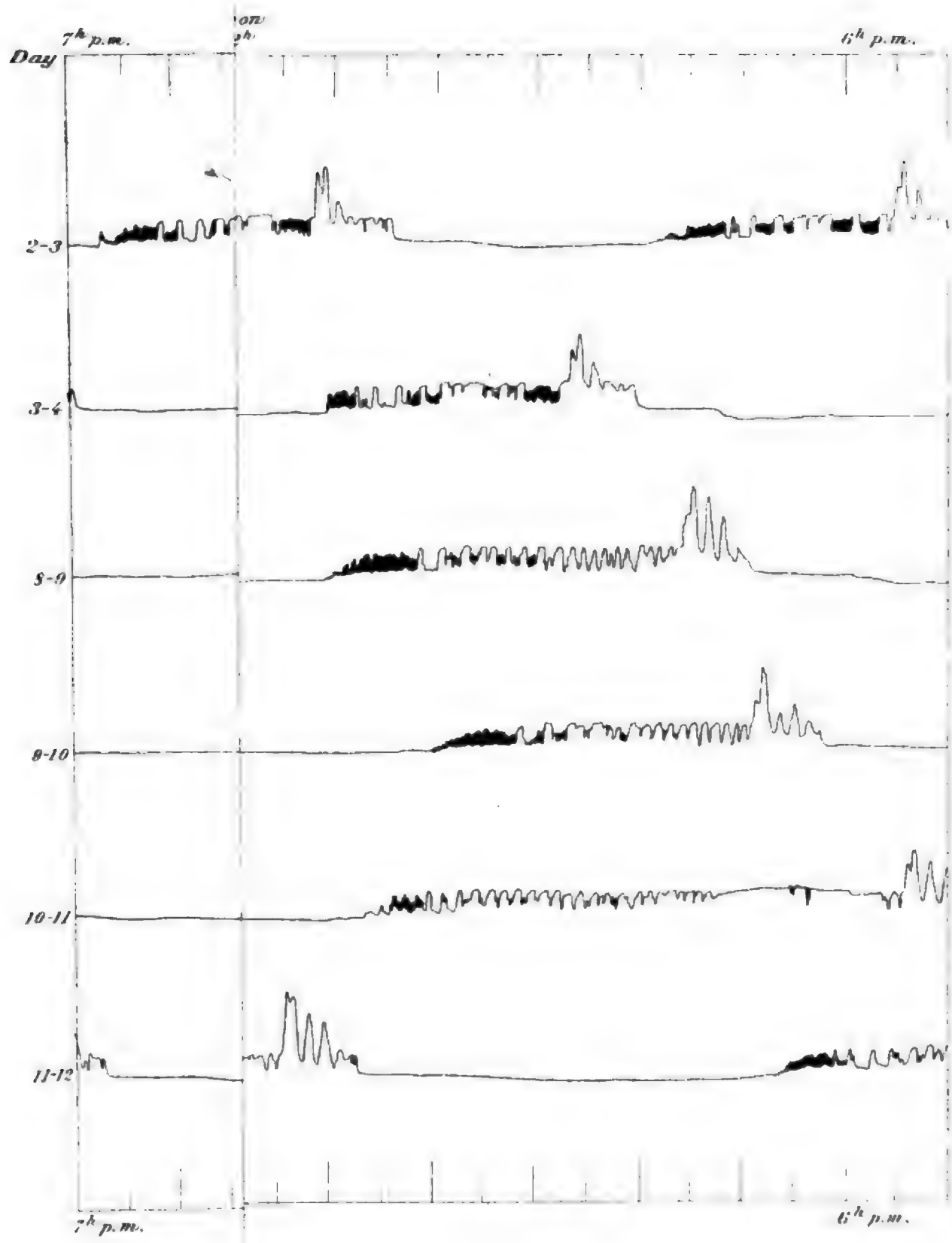
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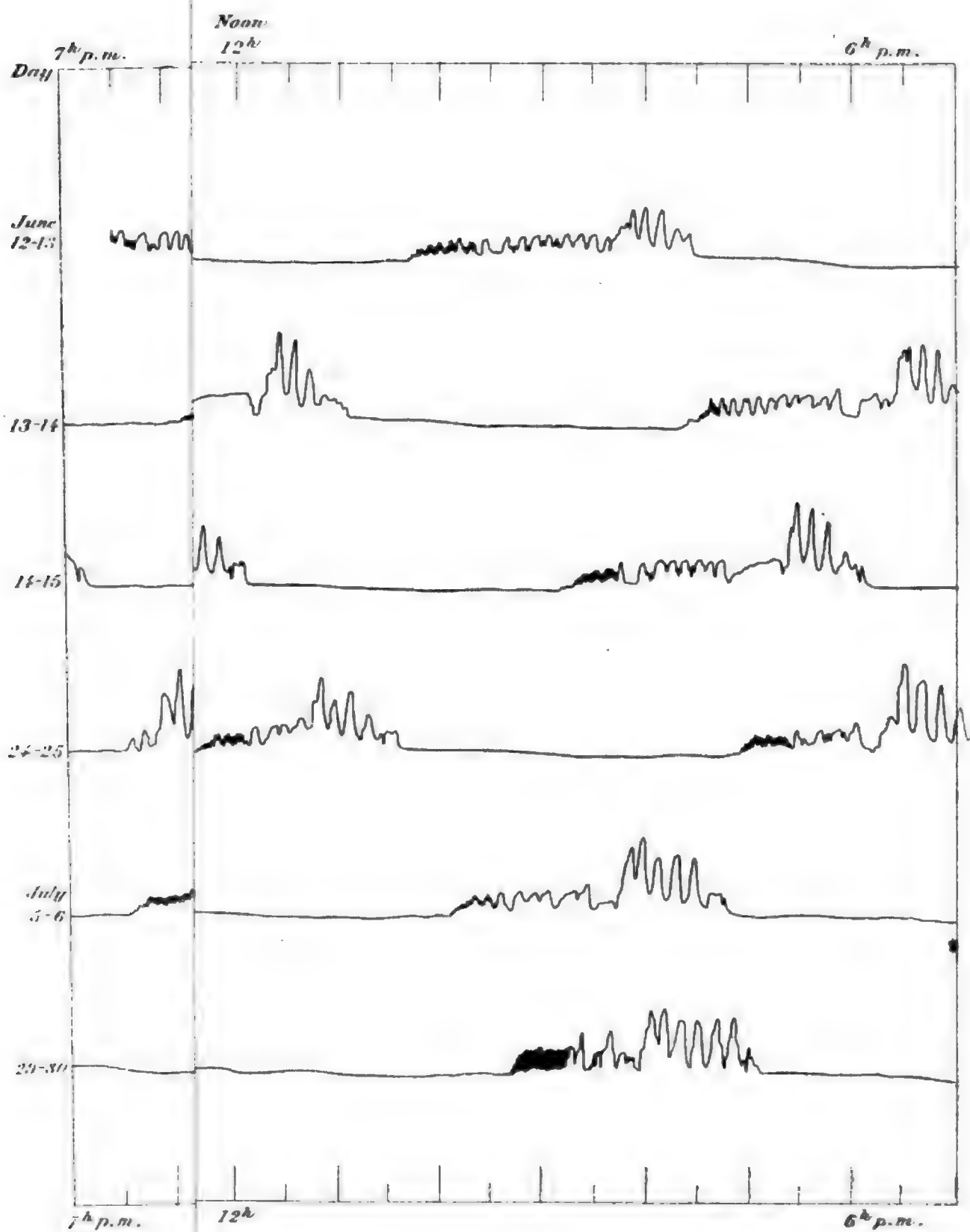


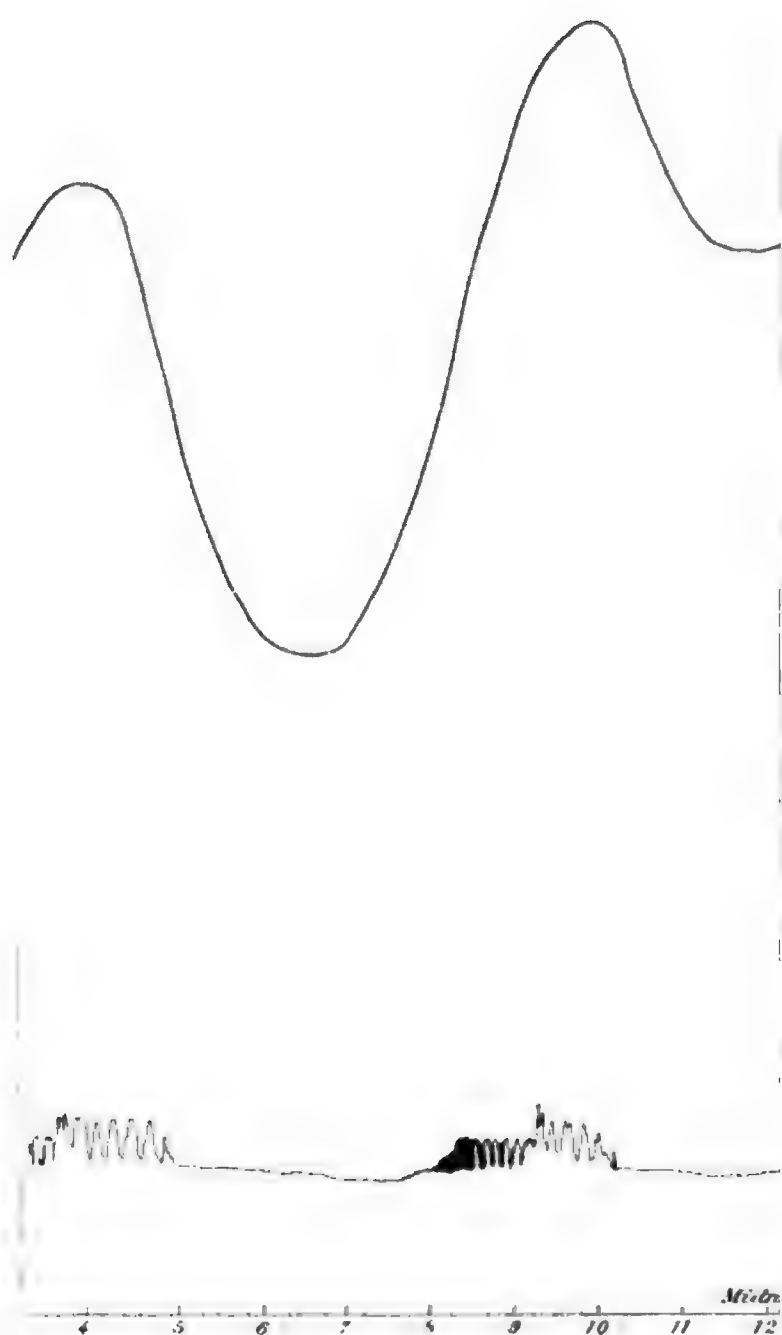


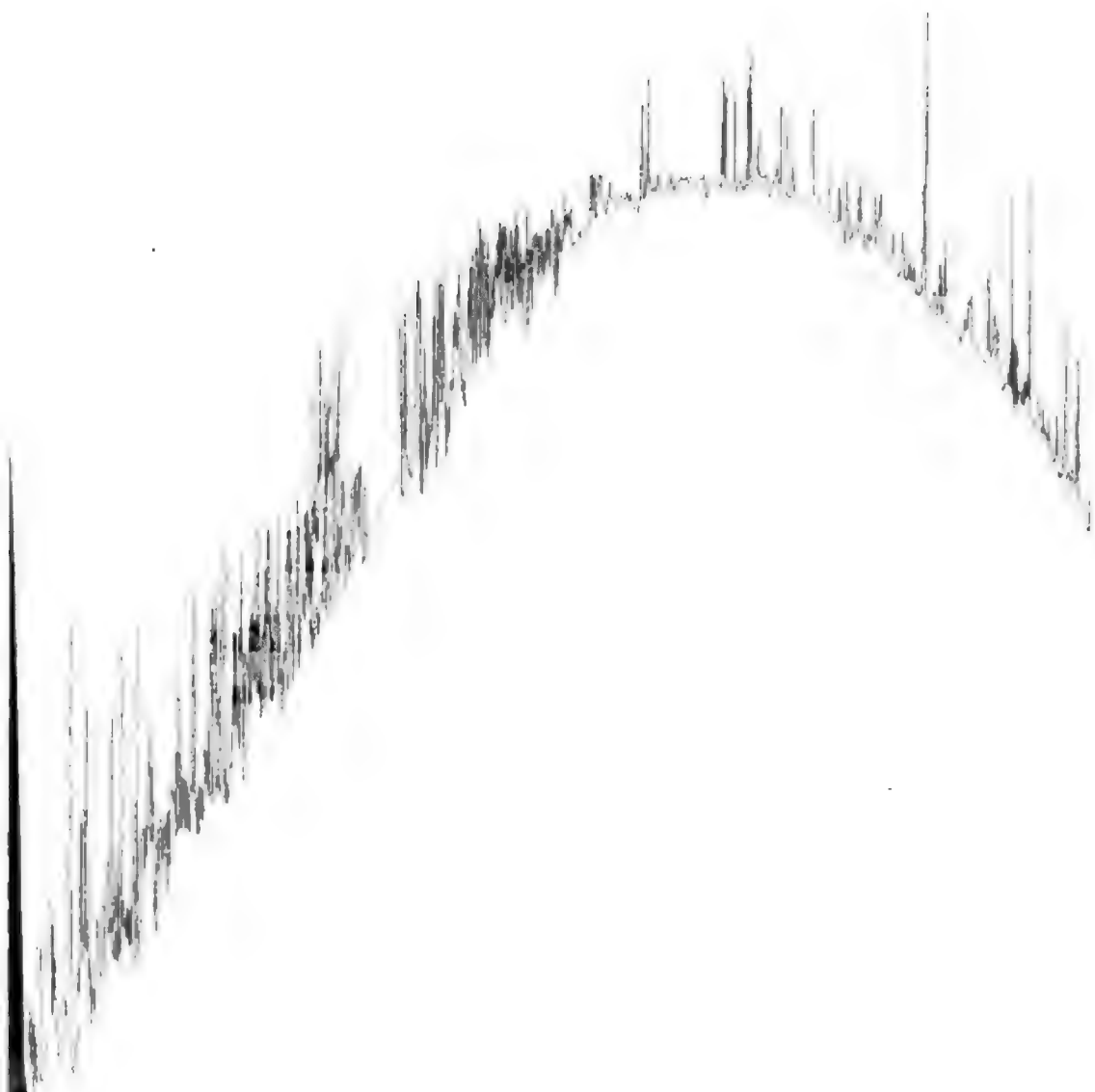












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TŌKYŌ, 1908.

PUBLICATION OF THE EARTHQUAKE INVESTIGATION COMMITTEE
IN FOREIGN LANGUAGES. No. 22. SECTION C, ART I.

The Ephemeral Volcanic Island in the Iwôjima Group.

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With Plates I-XII.

INTRODUCTION.

In the course of December 1904 (the 37th year of Meiji) a volcanic island was newly formed in the vicinity of Minami-Iwôjima which is situated at the southern extremity of the Fuji volcanic zone. The news was first reported in February of last year (1905) by some inhabitants of Iwôjima, and, as is fresh in our memory, was for a while an absorbing question with the public. In June last, at the request of the Earthquake Investigation Committee, I proceeded to the said island by the *Hyôgomaru* with a view to make an inspection there. But when I came near, to my great disappointment, I found it impossible to set foot upon the island, since the greater part of it was already worn out, leaving above the water a low reef just on the point of sinking. Moreover, the sea then raging, prevented me even from approaching the reef and obliged me to return without attaining the desired end. And if the present report gives the reader an impression that it is a long way from satisfactory or complete, I hope these circumstances will offer an excuse for that. Here I must express my heart-felt gratitude to Prof. Kotô who was kind enough to give me several valuable suggestions in studying my collected specimens, and without which, I fear, my report might have fallen still farther short of the mark.

The New Island was nothing more than a submarine volcano, heaved up above the level by eruption, and was situated about 3 nautical miles northeast of Minami-Iwôjima. It may safely be inferred from its position, that this submarine volcano was one of the Iwôjima volcanic islands representing part of the so-called Fuji volcanic zone; and for this reason it appears convenient to make a statement respecting the present volcanic islands of Iwôjima or Sulphur Island group before entering into the main question.

IWÔJIMA GROUP.

The volcanic islands of Iwôjima group, also called Volcano Islands (Plate I) comprehend three volcanic islands ranged nearly north-south between 141° and $141^{\circ} 30'$ east longitude and between 24° and $25^{\circ} 25'$ north latitude. Of these three islands the central one is the largest and bears the name of Naka-Iwôjima¹⁾ or simply Iwôjima (Sulphur Island); the one to the south Minami-Iwôjima (San Augustino Island), and the one to the north Kita-Iwôjima (San Alessandro Island). Kita-Iwôjima is situated 90 nautical miles southwest of Hahajima (Hillsborough Isl.) or 660 nautical miles distant from Yokohama, and Minami-Iwôjima, which is the southernmost limit of the Empire in this direction, is 740 nautical miles from Yokohama.

1. *Kita-Iwôjima (San Alessandro Isl.)*

Kita-Iwôjima is situated $25^{\circ} 25'$ north latitude and $141^{\circ} 16'$ east longitude. It is a volcano standing 2534 feet above the surface of the sea, about 12 km. in circumference, and 545 hectare in area. The coast line has become known in some measure, from the survey effected by Mr. Okamoto and others in 1904, but the topographic survey of the interior has not yet been made.

Fig. 1, Pl. II. is a topographic map of the island drawn from the survey made by Mr. Okamoto and from my own sketches. It will be seen therefrom that the outline of the island is nearly elliptical

1) Naka-Iwôjima means Middle Sulphur Island.

with no remarkable irregularities of coast line. The mountain is generally precipitous, and the summit is divided into two prominent peaks, north and south. The one to the south is the higher (2534 feet) and its top, being nearly always covered with dense clouds, is said to be rarely visible from its foot. In consequence, it is not yet certain that this summit has any hollow vent as seen in most volcanoes. However, besides the two above-mentioned peaks, there is a somewhat low isolated one to the northeast of the south peak, and the deep valley skirted by this low peak and the north and south peaks has a white-decayed precipice in the middle part, as if influenced by solfataric action, suggesting the trace of explosion crater.¹⁾

The mountain sides are very steep and directly lead to the sea without leaving any coastal plain around the island. Along the shoreline, however, there is a gravel beach of from 80 to 100 meters wide, with scattered big pebbles. It is a very noticeable fact that at the distance of about 100 meters from the water's edge the sea is very shallow, being only 2 or 3 fathoms deep, and even a small boat cannot approach the shore easily, owing to the waves usually raging there.

This submerged platform, or wave-cut terrace, together with the said gravel beach along the shore, marks the space which the water has conquered by dint of wave-cutting, since the formation of the island. Moreover, the steepness of the mountain sides (far steeper than the inclination of lava or tuff strata composing the volcano) must also be attributed to this rapid wave-cutting as well as the rapid formation of sea-cut cliff, for in such cases erosion plays a more important part compared to weathering which generally tends to reduce the angle of the slope; and the more resistant the material, the steeper the slope of the mountain, as is the case with Kita-Iwôjima.

Our landing and inspection being confined to the small sphere of Higashi-Ishinomura and neighbourhood on the eastern coast, I must confess that I could not obtain sufficient materials to show the geolo-

1) The position of the supposed explosion crater is shown by a dotted line in Fig. 1, Pl. II.

gical construction of the island. But, so far as I could observe, the greater part of the mountain is composed of a comparatively hard kind of volcanic agglomerate containing a sheet of lava, which is cut in every way by dykes of dark-coloured andesite. In the precipice along the shore, about 200 meters south of Higashi-Ishinomura, there are exposed four or more dykes of great dimension, some reaching about 300 meters in length, the grand appearance of which can be seen from the far distant sea (Fig. 2, Pl. II.).

(i) *The agglomerate-forming augite-andesite* is a hard and somewhat vesicular rock which contains abundant phenocrysts of feldspar in dark gray-coloured ground-mass. Its external appearance greatly resembles the agglomerate-forming andesite of Hahajima which is seen alternating with Nummulite-tuff. Under the microscope, it is found to be of holocrystalline-porphyrific structure, containing phenocrysts of plagioclase and altered augite (Fig. 3, Pl. IX.). The plagioclase, though it is fresh and transparent, contains in inclosures a small quantity of augite besides magnetite and some glassy substances. These inclosures are arranged zonally along the cleavage face of the plagioclase. Polysynthetic twin of albite type is very common and pericline twin is also occasionally found. Considering that the extinction angle at *P* face reaches even -37° , it is safely inferred that it belongs to the most basic anorthite. The porphyritic augite is usually altered into a bastite-like substance of greenish brown or yellowish brown colour, with dark secreted grains perhaps of magnetite on its peripheries and cracks. The same phenomenon presents itself in the agglomerate-forming augite-andesite of Hahajima. The ground-mass is composed of lath-shaped plagioclase, augite grains and magnetite, with no trace of glass-basis.

(ii) *The Dyke-andesite* is a porous dark gray-coloured rock of basaltic appearance. Those marginal parts which are in contact with agglomerate are especially glassy and abounding in pores. As phenocrysts there exist a great number of plagioclase and a

very few of augite, but no olivine. The plagioclase is transparent and full of glass inclosures, and polysynthetic twinning of albite type well developed in it. The wide extinction angle shows that it is of soda-line feldspar of basic composition. The augite is of light yellow-gray colour and weak pleochroism, with well-developed prismatic cleavages. The ground-mass is of hypocrystalline structure and is composed of microlites of plagioclase, augite and magnetite, with a small amount of some glassy substances. The pores of various sizes which exist in the rock are generally fringed with yellow oxide of iron (Fig. 4, Pl. IX).

Though the whole island except the southern side (with its steep inclination) is covered with a thick forest, the trunks are all short on account of the strong sea-wind which prevails. Only near the beaches and in the valleys less exposed to wind, tropical trees of evergreen broad leaves, such as *Calophyllum inophyllum* L., *Terminalia Catappa* L., *Hibiscus tiliaceus* L., *Hernandia peltata* Meisn., &c. are seen in comparatively good growth. Slow inclining talus places in the island, such as the neighborhood of Higashi-Ishinomura, are thickly covered with red laterite, and there sugar-canes, maize, sweet potatoes, gingers, etc. are cultivated. On the beach and the talus ground above mentioned, decomposition of soil is complete and no substance which bears any sign of recent eruption is to be found. This, to my mind, goes to prove that the island lost its activity long ago, in which respect it resembles Minami-Iwôjima and widely differs from Naka-Iwôjima.

I may add here that this island, like the other two, had been long uninhabited, till, in 1899 Mr. Ishino, an inhabitant of Hachijôjima, set his hand to the reclamation. Since then, the population has increased year by year, so that at present there are 36 families and 178 inhabitants in the east and the west Ishinomura.

Submarine Volcano near Kita-Iwôjima.

At the distance of about 3 nautical miles northwest of Kita-Iwôjima there is a submarine volcano. Once it emitted steam and

displayed a very grand spectacle.¹⁾ With the earthquake of 1889, the emission came to an end, but a shoal covering the space of about 2 miles from north to south still remains to mark its site, where the sea-water is always found muddy and disturbed.

2. *Iwôjima (Sulphur Island).*

This island, situated in the centre of the Iwôjima group, is the largest of the three sister islands.²⁾ It was discovered, along with the north and south Sulphur Islands, in the year 1784 or thereabouts, by Captain Gore who, after the death of the famous explorer Captain Cook, explored the Pacific Ocean on board the *Resolution*. As Captain Gore christened it Sulphur Island it bears the name of Iwôjima, but has come to be called Naka-Iwôjima, viz., Middle Sulphur Island in distinction to the north and south Iwôjima.

This island is like a gourd in shape, extending from southwest to northeast. It is more than 24 km. in circumference and 1895 hectare in area. Except at the neck, the island is surrounded by precipices facing the sea. The coast-line of the island, together with that of Kita-Iwôjima, was made known by the survey of Mr. Okamoto in the year 1904, but the relief of the interior has not yet been ascertained. Fig. 1, Plate III is a topographical map drawn on the basis of the contour of the island by Mr. Okamoto, to which I have added contour lines with the assistance of my own sketches and investigations of part of the island. From a scientific point of view, the construction of this island is of great interest. There stands a low tuff-volcano called Motoyama, which occupies the greater part of the island, in the southwestern extremity of which rises a cone-shaped volcano called Suribachiyama or Mount Pipe. These two volcanoes present a peculiar contrast, the sight of which is very impressive. Fig. 2, Plate III shows the view of the island in the southeastern direction from Nishiminato, the anchorage of regular

1) A sketch at the time of its activity is shown in a chart.

2) 21° 28' north latitude and 141° 13' east longitude.

liners; Fig. 3¹⁾ shows the view of the island due east on the way from Nishiminato to Minami-Iwôjima; and Fig. 4 is a distant view from the southeast. This last figure is drawn from sketches by the late Prof. Y. Kikuchi, who visited the spot in 1888. A comparison of these three figures will make it easy to picture the topography of the whole island. In natural features, as mentioned above, Naka-Iwôjima is of a unique character and no doubt the most interesting member of the Iwôjima group; but unfortunately we had not time for a close examination, spending only a few hours in inspecting a part of Motoyama. As regards Mt. Pipe, we had no opportunity of climbing it, and it is a matter of great regret that I cannot make a full report of this interesting volcanic island. We have, however, a report published in the "Tôyôgakugei-zasshi"²⁾, by the late Prof. Y. Kikuchi who landed the island and inspected more especially Mt. Pipe. Again, Dr. Johannes Petersen published, in his "Beiträge zur Petrographie von Sulphur Island, Peel Island, Hachijô and Miyakejima" (1890), a short report of Dr. Warburg (who visited and collected rocks there in 1887) together with a detailed account of his own microscopic investigation of the rocks. Although Motoyama occupies 96% of the whole island, it is a low plain hill only about 430 feet high above the sea and 200 feet lower than the Pipe; and it is entirely composed of yellow tuff, with no trace of lava-flows. Indeed, such another pure tuff-volcano is not found in any other parts of our country's possessions.

Motoyama-tuff is a light friable pumiceous tuff of pale yellowish red colour, the greater part consisting of decomposed pumice powder. Of this tuff, two different kinds may be recognised: one is fine-grained and homogeneous with minute black spots, and the other is somewhat coarse-grained, so that the component pumice fragments can be clearly observed with the naked eye. The latter is usually found forming a thin layer in the former.³⁾

1) Mt. Pipe is seen near in front.

2) A scientific journal written in Japanese. Kikuchi's report appears in No. 77 of this journal.

3) The former was mentioned by Dr. Petersen as tuff.

On pounding these two kinds, washing off the clay part produced by decomposition of pumice, removing the magnetite¹⁾ from the remaining sand, and then separating them by Thonlet's solution, it was found that there existed no distinction between them in point of mineral composition; that is to say, the minerals were apatite and monoclinic pyroxene that were separated by dense solution, the specific gravity of which was from 2.8 to 3.1.

The apatite is of a colourless transparent long prismatic crystal of very distinct outline. It is often 1 mm. long and is composed of ∞P , P and rarely oP . What is most wonderful in it is the glass-inclosures, which often assume the form of parent mineral after the style of negative crystal. Most of them contain immovable bubbles (Fig. 1, Pl. XI). Inclosures are occasionally light brown, but generally colourless, some with a dark opaque substance in one part. Dr. Petersen says that some of the inclosures are liquid.

The monoclinic pyroxene is generally separated in irregular broken pieces. It is fresh and sharply edged, and is composed of ∞P , $\infty P\bar{\infty}$, $\infty P\tilde{\infty}$, P and rarely oP . The pleochroism is uncommonly conspicuous and varies between c smaragd-green, b olive-green and a grayish green. $c : c$ in the symmetrical plane varies from 50° to 54° . It contains a great quantity of acicular apatite, magnetite and glassy substances in inclosures.

The feldspar may be separated by a solution of from 2.5 to 2.37 specific gravity and is obtained in cleavage slices or in irregular broken pieces. It is in most cases decomposed, and some of the pieces are covered with colourless micaceous scales, nearly hexagonal with round margins and with a gray-coloured spot in each centre, as shown in Fig. 4, Plate XII, or partly altered into clayey substance. Dr. Petersen infers this feldspar to be orthoclase from the absence of twin laminae and from the

1) Magnetite occurs in great quantity in octahedral crystals or in irregular grains.

optical orientation on *P* and *M*; but, besides this questionable orthoclase, twinned feldspar unobserved by Dr. Petersen can be found in considerable abundance. This twinned feldspar is in all probability oligoclase as judged by optical relation. It contains brown and colourless glass with gas bubbles and apatite needles in inclosures.

In short, this rock is of an entirely different nature from those ejected from the Pipe with respect to the nature of its augite and feldspar, and the absence of olivine; neither does any relation seem to exist between the rock in question and those of the New Island with the exception of the resemblance of the apatites.¹⁾

As has already been said, though Motoyama-tuff is uniform in texture, yet some coarse-grained parts are imbedded everywhere; so, as a whole mass, it clearly presents marks of bedding, and the whole stratum descends obliquely in all directions, dipping slowly from the central part of the mountain. This stratum towards the sea assumes a terrace-like form, with precipices presenting remarkable traces of wave abrasion.²⁾ The flights of these terraces, of tuff consolidated at the sea-bottom, terminating in the afore-said manner or found in the form of "Tischstein," are shown in Fig. 2, Plate VI. The formation is a relic of abrasion, and is a clear proof of the upheaval of ground in Motoyama. I have also discovered two other wonderful facts strongly confirming my inference. One is that, as is shown in Fig. 1, Plate VI, at the height of some 430 feet in the mountain, madrepora corals cluster together here and there, forming thin coral reefs, most of which belong to the living *Stylophora* species (Plate VII). These coral reefs struck me with delight when I found that they bore very little mark of weathering, still retaining their life appearance though blackened on their surface, and standing in bold relief upon the tuff. This goes to show that the elevation of the

1) Compare Fig. 1 and Fig. 2 in Plate XI.

2) Vid sketches of Plate III.

volcano is of much later occurrence than is generally supposed. The other fact is that, together with these coral reefs, many tuff-pebbles, which assume the round flattened form so characteristic of a surf-beaten beach, are found everywhere on the mountain. Thus there is no room for doubt that this island was formed with suddenness not long ago, and from this fact it is also clear that the tuff of Motoyama is a sedimentary deposit of the sea-bottom.

I may here add that according to some inhabitants who immigrated here some years ago, the land is still uprising, most conspicuously so at the neck, east of Mt. Pipe. Its northern shore was formerly the anchorage of vessels which visited the place, but owing to the gradual rising of the sea-bottom, it ceased to afford shelter for vessels, and mariners have been obliged to choose Nishiminato instead.

Thus we see it is of comparatively recent occurrence that the whole mass of Motoyama volcano was elevated above the surface of the sea; but the formation of tuff on the sea-bottom is no doubt anterior to that of Mt. Pipe, as will be proved below. Since the formation of tuff, Motoyama has gradually diminished in activity, till at present it has only about ten solfataras on the top. As is shown in the topographical map in Plate III, the solfataras are scattered in a comparatively large area; moreover, each solfatara seems to have had its own fate, and frequently changed its position. It may also be inferred by the presence of the above-mentioned corals in their midst that some of these solfataras were produced after the appearance of the volcano above the surface of the sea. Among these solfataras, the central Motoyama-solfatara and Furuyama-solfatara about 150 m. north of the above are ejecting sulphurous vapours in the greatest abundance at the present time. Again, on the shore of Nishiminato, the only landing place of the island, a hot spring is said to be seen.

It is a fact no less noticeable that the entire surface of Motoyama is covered with volcanic sand or lapilli varying in size from a rice-grain to that of a pea. These volcanic sand and lapilli are com-

posed of various volcanic ejectamenta, such as black obsidian, spongy pumice, reddish lava scorïæ, dark-coloured lava fragments with phenocrysts of feldspar and isolated feldspar crystals, etc. They are evidently not from Motoyama, but from Mt. Pipe, seeing that the petrographical nature of the sand bears no resemblance to the ejectamenta of the former but is similar to those of the latter, and bigger grains are found in greater quantities as we approach Mt. Pipe. Dr. Warburg and Dr. Petersen were certainly mistaken in surmising that feldspar crystals and other ejecta had been separated from Motoyama-tuff by weathering.

The most interesting of these volcanic sands is the crystal bomb of feldspar coated with a thin crust of black glass, some samples of which are so large as to reach 15 mm. in length. The crystal habit is tabular owing to the development of *M* face, and in most cases two or three crystals penetrate each other obliquely, thus forming a kind of twin. The surfaces of the crystals are generally rough, and both their angles and edges are worn and more or less rounded, though not utterly obscure. In them *M* is best developed, *P*, *T* and *l* are in narrow belts, and Carlsbad twin is invariably developed. From their extinction angles which are -1° on *P* and -5° on *M*, it may be inferred that they are of a kind of andesine. The crystals, though quite fresh, are full of yellowish brown glass-inclosures which are arranged zonally along the cleavage-face. In these respects, they bear affinity to the feldspar in the pumice of the New Island.

As mentioned before, this feldspar sand is generally crusted with a thin black glassy coating; even where part of the coating is worn out by weathering, a sponge-like glass still remains glittering in the reentrant angle of the crystals. This glass coating is very similar to the ground-mass of glassy andesite forming part of Mt. Pipe, from which we see that this feldspar sand, as is the case with the anorthite bomb at Miyakejima¹⁾ already studied by the late Prof.

1) On Anorthite from Miyakejima. The Journal of the College of Science, Imper. Univ. Vol. II.

Kikuchi, was once floating in magma at the crater bottom of the volcano Pipe, and was ejected together with other volcanic sands during the subsequent eruptions. Thus the feldspar bombs in these two places—one andesine and the other anorthite—are different in composition and crystal habit, but the same in the manner of ejection. It is an interesting fact that similar feldspar bombs are also found in Ôshima and Hachijôjima, so that this phenomenon seems to be characteristic of the Fuji volcanic zone.

The volcanic sand mixed with feldspar crystals is found lying thicker on the ground as we approach Mt. Pipe, at some points reaching even the thickness of 10 or 12 inches. In the vicinity of the Pipe there are scattered lava blocks of various sizes and shapes, half buried in the sands. They are somewhat scoriaceous and have tabular phenocrysts of plagioclase in the ground-mass of dark gray colour. Petrographically they are of the same quality as a kind of lava which composes the cone of the Pipe. The most noticeable thing about these lava blocks is that wind ablation¹⁾ is very conspicuous in them, and is expressed in various stages: thus some of them have their exposed parts considerably eroded into a peculiar conical form whilst they almost keep their original form only in the lower parts buried in the sands; some have a crown-like top whilst they have the feet of their exposed portions greatly worn; and others have lost even their crowns through the influence of the wind, so that their surface is reduced to the same level as that of the sands.²⁾

To conclude: Motayama is an elevated submarine volcano, which once ejected a great quantity of puniceous ashes and formed the so-called Motoyama-tuff under water; soon after the formation of the tuff was completed, Motoyama became weakened in volcanic activity without effusing any lava, and at the same time heaved itself up at a rapid rate, until its top got to the height of 430 feet above the

1) The prevailing wind in the island is from the south.

2) cf. *Journal of Geography* (in Japanese), No. 202. "Geographical Trip to the New Sulphur Island" by Mr. Satô (*Rigakushi*).

sea level. This upheaval of the mountain, be it remembered, seems to be still going on. .

Suribachiyama or Mt. Pipe.—We found no opportunity of inspecting this mountain, of which, however, an exploration was made by both the late Prof. Kikuchi and Dr. Warburg.¹⁾ The former's report appeared in the "Tôyôgakugei-zasshi" and the latter's in Dr. Petersen's "Beiträge", as before mentioned, and it is to these reports as well as Petersen's studies on rocks that I owe the following description of the structure of the volcano.

Mt. Pipe, entirely different from Motoyama in all respects, is a strato-volcano composed of ash layers and lava sheets. It forms a truncated cone, standing about 640 feet above the sea-level and 200 feet higher than Motoyama. As is the case with many volcanoes, it has in its top a crater in the shape of a bowl or the Japanese "suribachi"; hence the name. There are two crevices ejecting steam, one on the south and the other on the west side; and the former has a sublimate of sulphur, alum, gypsum and potassium salt. On the northern side of the crater a deep valley (perhaps barranco) opens upon the sea. Alternating strata of ashes and lavas are found sloping down from the crater on all sides. Prof. Kikuchi writes that the foundation of the volcano Pipe is a horizontal layer of gray sandy volcanic ashes, which is composed of glassy substance probably sedimented in the water (Fig. 5a, Pl. III). The professor, as it seems, considered that it was of the same origin as the so-called Motoyama-tuff, but, I must venture to say, there is not sufficient reason to believe in their brotherhood. Covering this fundamental ash layer, there are some lava beds, which form a precipice of about 100 feet in height (Fig. 5b, Pl. III), partly cracked into a vertical prism. It is these lavas that are mentioned by Dr. Petersen as *glasiger Augitandesit*, *Bimssteinartiger Augitandesit*, *Schwefelführender Augitandesit*, &c. Most of them are in the form of black vitrophyric rocks, containing tabular crystals of plagioclase in a compact or porous ground-

1) loc. cit., p. 7.

mass. Under the microscope, oligoclase, monoclinic augite, olivine, apatite and magnetite are recognizable. Of the ground-mass, some are hyalopilitic and the others glassy, all containing augite-microlites and other devitrified products. Those parts of the lava which were subjected to the influence of solfataric action are now bleached into white or light gray colour. Overlying these lava beds, and composing the greater part of the volcano, are gray ashes containing plagioclase, augite, olivine, magnetite, apatite, besides compact or pumiceous glasses, together with various decomposition products.

In a word, Mt. Pipe, very different from Motoyama, is a strato-volcano active until recent times. After the first ejection of volcanic ashes, hard lava-sheets were formed, which made the mountain solid and precipitous, forming itself into a truncated cone quite unlike that of Motoyama; and it is of recent occurrence that it ejected the above-mentioned feldspar crystals and various volcanic sands now covering the whole island.

Though we may assert that these two volcanoes entirely differ from each other in their structure and composition, we cannot say that they have no relation whatever to each other. Indeed, the fact that after throwing out volcanic ashes, Motoyama became inactive without any effusion of lava, may have been the result of the subterranean magma finding its own way, which culminated in the formation of the present strato-volcano of Mt. Pipe.

3. *Minami-Iwôjima (San Augustino Island).*

Minami-Iwôjima or South Sulphur Island is the southern-most of the three principal islands of Iwôjima group, and its geographical position is of $24^{\circ} 14'$ north latitude and $141^{\circ} 29'$ east longitude; being in about the same latitude as the middle part of Formosa.

This island, 3039 feet high, is a strato-volcano of a conic form and of the same type as the volcano Pipe in Naka-Iwôjima and the volcano of Kita-Iwôjima. The outline of the island is almost spherical and it is only 8 km. in circumference. The mountain sides are all

very steep and slope precipitously to the sea with an inclination of about 40° , without leaving any level ground at the foot. The top is almost always invisible from the sea, being covered with dense clouds. (Fig. 2, Pl. V and Fig. 1, Pl. IV.)

The mountain sides are overgrown with small bushes down to the middle height, but below no vegetation is found and bare agglomerates and lavas rise above the ground at a dip of about 20° . Only the northeastern side with no verdure is entirely of rust colour from the ashes which, it is said, covered it, at the time of the eruption of the New Island.

This island has not been inhabited for a long time, so that our knowledge of it is very limited.

THE NEW ISLAND.

History of its Eruption.—This island, the exploration of which was the chief object of our trip, made its appearance in November 1904, 3 nautical miles northeast of Minami-Iwôjima. On approaching it, as mentioned in the Introduction, I found the greater part had already been abraded away, and lost for ever the opportunity of inspecting it in person, so that I am in no position to give any detailed account of its formation, and all I can now do, is to state my scientific inference on the subject from the report of an exploration effected by some inhabitants of Iwôjima soon after the eruption. The following is a translation of some extracts from their report (in Japanese):

“A noise like the roaring of a cannon was heard from the south of Iwôjima on and after November 14th, the 37th year of Meiji (1904).

On the 28th of the same month, at 8 p.m. a feather of smoke was seen about 3 nautical miles east of M.-Iwôjima. At first, we thought that it was the smoke from a man-of-war at sea, and it was about an hour later when dark smoke came to be seen hurled up in greater quantities that we realised the cause of the phenomenon. That day, however, there was no such noise as had been heard before. After a while, the dark smoke changed its colour now

into white and then into red, sometimes rising in full force and the next moment subsiding. At night, however, nothing could be seen.

On the 5th of December, we first caught sight of an islet lying amidst the smoke.

On the 8th of the same month, the said new island had the appearance of three smaller ones grouped together; but of-course it was not certain whether a group of three really existed or simply appeared to exist, owing to the presence of vapour brewed by the eruption.

On the morning of the 12th of the same month, the sky cleared up and the island made its full appearance. It was then single, looking somewhat higher in the eastern part, and level in the western.

On the 14th of the same month, the island assumed the appearance of a long one, at one time emitting white smoke and at another dark smoke from the middle.

On January 2nd of the 28th year of Meiji (1905), the island changed in shape growing higher in the western part, and emitting a little white smoke from the mid part. About 3 o'clock p.m., however, there burst forth voluminous dark smoke which was followed by white after twenty or thirty minutes.

On the 5th of January, the immigrants in Iwôjima met together and decided to attempt an exploration there and report its result to the island-office. When volunteers for the proposed adventure were called for, ten men responded, all determined to sail to the island in a boat and a canoe.

They commenced preparations on January 6th, and made several attempts to put to sea, failing each time on account of bad weather.

The weather becoming fine on January 31st, they at last succeeded in getting to M.-Iwôjima. This island being near the new volcanic island, nearly the whole surface was covered with ashes and the plants had all withered, except in a small part in the south-west. Much débris of pumice was found thrown up on the coast round the island.

On the 1st of February, they sailed out from M.-Iwôjima and arrived at the New Island. The high waves on the shore made landing very difficult; moreover, as it was only a few days after the eruption, the party was exposed to great danger in the attempt.

* * * * *

They then made a step survey and sketch of the island, and collected samples of stones. The island, as will be seen from the sketch in the appendage (Fig. 4, Pl. IV.), was about 3 miles in circumference, the highest portion standing about 480 feet above the sea. There was a small pond in the northern flank about half a mile in circumference, where vapour was rising profusely. In all probability it had been a crater. The north bank of the pond being only 3 or 4 feet high, the sea-water probably had used to run into the pond when high waves came. The south bank was precipitous and its highest portion formed the summit of the island. Though the island was composed of hardened rocks, the surface was all covered with loose ashes about 5 or 6 inches in thickness. It was about 200 acres in area and almost flat on the top, surrounded by narrow shore-plain 120 or 240 feet wide. * * * * *

The report of the immigrants above quoted tells us that they had heard sounds like cannon since the 14th of November—a very common phenomenon foreboding the coming eruption of a volcano; and it may be safely inferred that the vapour at the bottom of the crater was already growing active, its expansion causing the movement of the magma. At last the eruption began in earnest at 10 a.m. on the 28th of the same month with the bursting forth of smoke; and the island made its appearance on the 5th of December, though it changed its shape and the colour of its smoke very often. The white smoke showed that mere vapour unaccompanied by volcanic ashes was then being ejected, and the change of its colour into black or red told that volcanic ashes together with vapour had begun to be thrown forth in large volumes. As regards the changes in the shape of the island during its eruption, they may be accounted for by the con-

jecture that, while large quantities of new ashes were accumulated at one point, those which had already been accumulated at another were blown away by explosions. In other words, the balance of these two controverting processes, constructive and destructive, must have determined the shape of the island. I feel still more confirmed in this conjecture when we consider that its centre of eruption seems to have changed from time to time.

What makes me more regretful than anything else is that we are unable to ascertain the component materials of the island, since no rocks were collected there, except pumice-débris which had been beached by the waves. It seems that these pumice-débris are part of what were effused in a lava-flow into the sea-bottom during the eruption and were broken off and thrown upon the beach by the waves. Mr. Azuma, one of the explorers, told me that what is mentioned as "rock" in the report, which formed the frame of the island, was of the same quality as the yellow tuff of Motoyama in Iwôjima. Though of course it is not to be believed that the rock was entirely of the same class as the tuff of Motoyama, at least it is evident that the New Island was not composed of any resistant hard lava. On examining the "ashes" which are described in the report as having covered the "rock" to the thickness of 5 or 6 inches, I found that they were a fine silt of light gray, or nothing but pumice in powdery form; and under the microscope, I also found them to contain the same plagioclase and augite as are seen in the pumice blocks collected. It is most probable that the New Island was constructed of loose volcanic products as is the case with many marine volcanoes, considering that the shape of the island often changed during the eruption, as mentioned in the report of the explorers.

The next subject which demands our investigation is the shape of the island. According to the report and the sketch by the explorers, the island was at first of egg-shape about 3 miles in circumference and 200 acres in area. The highest point, 480 feet above the surface of the sea, was in the northern part, which formed the big-

ger end of the egg, the surface of the island slowly inclining toward the south (the dip being about 12° according to the explorers' sketch) with no ragged contours, while the northern is very steep, nearly vertical. Beneath this precipice, there was a long elliptical pond about 2400 feet in circumference, the northern side surrounded with a barrier only 3 or 4 feet high; and from some parts of the pond vapour was rising. From this fact, we may clearly conceive that the pond of the northern end was the centre of eruption or crater, that the island was but a portion of the crater rim appearing above the surface of the sea, and that the barrier bordering the north margin of the crater pond was of pumice-débris, drifted upon the island by the wind like those forming the beach round the island. The formation of such a pumice barrier was probably owing to the presence of a hidden reef forming a portion of the crater rim in the north of the pond. It is also obvious, from the explorers' report, that explosion had played an important rôle in the eruption of the New Island, that the greater part of the crater rim once formed there had been demolished by the explosion, and that the New Island was nothing more than that portion of the crater wall which remained free from the influence of explosion.

I believe that the pumice which was brought back by the explorers is part of the lava effused from the crater after its chief explosion. This may be proved from the nature of the lava which will be referred to below, as well as by the fact that the substance composing the body of the island was, as above mentioned, not rock of this kind, but loose volcanic ashes or tuffs. The vomited lava did not amount to such a large quantity as to form part of the island above the sea, and yet was sufficient to form a belt of gravel beach round the island with its broken pieces by aid of the waves. An enormous quantity of pumice fragments was also scattered about like shrapnel bullets by the eruption and carried away by the current to considerable distances, arriving at the Bonin Islands and even as far as the eastern coast of Honshin and Riukin Islands. In April 1906, I

collected a number of pieces of drift pumice on the eastern coast of Awa Peninsula, of which the petrographic similarity with those of the New Island has been proved by myself by microscopical investigations. Also, according to the report of Dr. Nakamura, Director of the Central Meteorological Observatory of Japan, a great amount of pumice-débris arrived at the coast of Ishigakijima in Yayema Group, Riukiu, from the middle of May 1905 to the beginning of June of the same year.

Petrography of the Lava of the New Island.

(Olivine-augite-andesite)

a.) *Microscopic Features.* The samples given me for investigation are a dark brown vitrophyric rock, consisting of two different parts, obsidian and pumice. The former, as its pores increase, gradually passes into the latter, so that the manner of gradation is observable in one sample. Plate VIII is the photograph of one of these samples, the lower part being of obsidian, the upper part of pumice, and the middle of both in a transitional condition. Such an orderly transition of these two parts goes to prove that they were originally of the same lava. Perhaps the upper portion of the lava, which naturally comes in contact with sea-water, was consolidated into a sponge-like pumice on account of its sudden cooling, while the lower portion where the cooling must have been comparatively slow, was consolidated into compact obsidian. Under the microscope, no substantial difference can be found between the two.

1.) *Obsidian Section.*—It is of a brownish black colour and pitch-like lustre, and presents conchoidal fracture as is usual with this class of rocks. It bears comparatively large cracks, occasionally 3 mm. wide, looking as if cut out by a knife, besides smaller ones running across in every direction. These cracks, however, are comparatively shallow (none being deeper than 2 cm.), and confine themselves within the section of obsidian, never extending into that of pumice. The ends of the cracks are never sharp, but always dull.

When the lava was about to cool and consolidate itself into masses in the water, large cracks were at once formed by the contraction of the masses, and no sooner were the walls of cracks suddenly cooled by the intrusion of sea-water, than the second cracks were produced, and so on. This may be clearly proved by the right angle at which the later-made cracks run to the surface of those which were made immediately before. If the cracks had not been formed, the obsidian would then have remained lying forever at the bottom of the sea and might not have come to our hands.

2.) Pumice Section.—It has a light brown colour, with somewhat silky lustre, and has large irregular pores, the greatest diameter of the largest one reaching 2 cm., besides smaller but deeper ones quite close to one another like those of a sponge. Both larger and smaller pores are generally lengthened at right angles to the surface of the boundary near the obsidian section, and turn in every direction at some distance from the boundary. But those forming a set go parallel to each other, as is seen in ordinary pumice. This is worthy of notice, because it is intimately related to the origin of pores. To my thinking, this is how the pores came into existence. When lava streamed out, the water in the molten lava turned into vapour, went up in innumerable bubbles, and formed viscous masses full of bubbles on the upper part of the flow. Thus, these masses of lava were consolidated into pumice in that condition. Larger bubbles were formed in the masses by accidental amalgamation of smaller ones, and subsequently consolidated into larger pores.

In the pumice section, as in the obsidian, tabular phenocrysts of feldspar and rarely small phenocrysts of augite and olivine can be seen with the naked eye. The feldspar is of a dull colour containing numerous glass inclosures, which are usually crowded in the middle of the crystal. The tabular form of the feldspar is very pronounced, owing to the development of brachypinacoid. Binary Carlsbad twin is not uncommon.

In the pumice section there is no sign of the presence of distinct

cracks as in the case of the obsidian section, but this section is somewhat more easily fractured perpendicular to the longitudinal direction of its pores.

Some of the pumices which were abundantly found on the coasts of the Bonin Islands differ a bit in nature from that above mentioned. Prof. Kotô made microscopic examinations of some of these pumices, and found that they contain a great quantity of rhombic pyroxene rare in that of the New Island; from which it becomes quite clear that divers kinds of pumices arrived at the Bonin Islands. We can assume from this fact that there are frequent submarine eruptions at the bottom of the great ocean especially in the neighborhood of the Fuji volcanic zone, which escape our attention.

b.) Microphysiography. For the purpose of microscopic examination, I cut the obsidian section into thin slides, and treating the pumice section by Thoulet's solution, examined the two separately. This revealed to me that its mineral components were magnetite, apatite, olivine, monoclinic pyroxene, rhombic pyroxene and plagioclase (here named in order of individualization). These occur in phenocryst in the ground-mass of light brown colour (Fig. 1, 2, Pl. IX; Fig. 1, 2, 3, Pl. X).

Magnetite occurs either in irregular grains or in cubic crystals with more or less rounded margins. It is often enclosed within other essential components, especially augites. This readily leads to the conclusion that it is the first of the individualization products. Apart from this no metallic mineral can be found.

Apatite occurs in prismatic crystals of a regular outline and its transverse section is hexagonal. It terminates either in P or in P and oP, and has a cleavage characteristic of this mineral crossing the main axis. It demands our special attention in this that it has glass inclosures of a light brown colour having the form of negative crystal as in the case of apatite in Motoyama-tuff. Many of the inclosures contain immovable air-bubbles (Fig. 2, Pl. XI).

Olivine, though less than one fifth of augite in quantity, is found within almost every thin slide, and is separated together with augite

and apatite, by means of Thoulet's solution of 3.1 or 3.2 in specific gravity. It does not exceed 2 mm. in diameter. The surface of the crystal is corroded for the most part, showing sections of imperfect square or of an utterly irregular outline. Observed faces are $\alpha\bar{P}\alpha$, $\alpha\bar{P}\alpha$, αP , $\bar{P}\alpha$, αP , P , etc. It is characterized by its strong refracting power and its vivid polarization colour. Though it contains glass and apatite needles as inclusions, the quantity is not so great as in the case of feldspar, and there is rarely seen a pocket-like intrusion of glassy ground-mass as shown in Fig. 1, Pl. XII. It is always fresh and no trace of serpentinization is found.

Monoclinic pyroxene in phenocryst, is next to plagioclase in quantity and equal to olivine in size, occurring in short prismatic crystals surrounded by sharp margins, in which αP , $\alpha\bar{P}\alpha$, $\alpha\bar{P}\alpha$, $-P$ (or P) are found (Fig. 3-6, Pl. XI). Sometimes it is twinned on $\alpha\bar{P}\alpha$ (Fig. 7, Pl. XI). The colour is very characteristic, and varies between a yellowish gray, b and c yellowish green, though not distinct. The polarization colour is strong, and the maximum extinction angle on $\alpha\bar{P}\alpha$ measures 46° - 48° . Prismatic cleavage appears in coarse lamellar sutures, besides other irregular fissures. Inclosures are very frequent. As in the case of olivine, glass with air-bubbles, apatite prisms of comparatively large size and magnetite crystals are the most common of inclosures. These inclosures do not run either zonally or centrally as in plagioclase, but some of apatite crystals and glass-inclosures lie parallel to some domal faces (Fig. 7, Pl. XI). This is rather singular. The deep intrusions of ground-mass may sometimes be seen, as is the case with olivine. Its specific gravity is about 3.2.

Beside the monoclinic pyroxene just mentioned, there are occasionally yellowish blue rhombic pyroxenes which exhibit parallel extinction. Pleochroism is distinct, varying between c yellowish blue and a, b bluish yellow. Some of them represent hypidiomorphic relation with plagioclase.

Plagioclase occurs in tabular crystals on account of the large development of M , and the largest diameter sometimes measures 6 mm.

towards the brachy-axis. It has four faces P , y , T and l , besides M ; but y is sometimes wanting and r (?) seems to take its place. The outline is regular, usually fresh and transparent, but it contains plenty of acicular or short prismatic crystals of apatite and brown glass with air-bubbles in inclosures. Most of the glass-inclosures extend flat along the faces of basal or brachypinacoidal cleavage with edges parallel to a crystal face. In some cases they continue without interruption in a peculiar manner along cleavage faces as shown in Fig. 3, Pl. XII. Large crystals contain so many of glass-inclosures that the plate about 1 mm. thick can hardly transmit light. Thus large crystals usually present a dark gray colour to the naked eye. Even in such crystal as abounds in inclosures, the inclosures crowd the centre, leaving a narrow transparent zone in its periphery. In this transparent zone only a few rows of glass-inclosures run parallel to the crystal face, and many lines of growth can be seen. The twin-lamellæ of albite type can clearly be observed in the section of P - y zone or in the cleavage slice along P face. In large crystals, twins of Carlsbad type are commonly developed, but no pericline twins are seen. Extinction angles on P and M in a cleavage slice are on the average of $+1.7^\circ$ and $+7^\circ$ in Schuster's meaning respectively. This number shows that the plagioclase is oligoclase near $\text{Ab}_{78}\text{An}_{22}$ (Fig. 3, Pl. X.).

Ground-mass is composed of glass of light brown colour. Fluxion structure is indistinct, and no kind of crystallites could be seen. Nevertheless, it is of special interest that the quantity of microlitic prisms of monoclinic pyroxene (Fig. 5, Pl. XII.) are irregularly scattered. The largest of these augite-microlites is $\frac{1}{2}$ mm. long and $\frac{1}{10}$ mm. wide, and the smallest does not reach $\frac{1}{10}$ mm. in length. The longitudinal section is rectangular, and each end of it always curved and often indented. The indentation rarely runs deep into the crystal, partly in the form of glass-inclosures. The cross section is octagonal or square. What is most interesting in it is that two or more crystals by intersecting each other form penetration-twins of the shape of

the letter X, of a cross or of a wheel. A few examples are illustrated in Fig. 5, Pl. XII. It is of light yellowish green colour with no pleochroism. The largest extinction angle is 52° to the main axis. These little augite crystals are not found in enclosures even in feldspars which are of later crystallization than porphyritic augite and undoubtedly belong to the second phase of crystallization.

Here it must be added, that in the phenocrysts of augite there is rarely found such a phenomenal crystal as is illustrated in Fig. 6, Pl. XII, which shows the face of clinopinacoid. It should be noticed that that part of the face which is covered by the diagonals drawn through the antagonistic angles of the rhombic crystal face is particularly prominent and presents a smooth shining appearance while the remaining part of the face between these diagonals is rough, sunken and imperfectly developed. This imperfect crystal makes us recall skeleton crystals (Fig. 7, Pl. XII) of monoclinic pyroxene which are found in glassy augite-andesite of Mt. Pipe in Iwôjima, to which Dr. Peterson called special attention.

In a word, the lava of the new island in question was vitrophyric rock of intermediate composition rarely found in the volcanoes of our country, and bore family resemblance to the glassy andesite of Mt. Pipe in Iwôjima described by Dr. Petersen, in the crystal habit and the optical properties of its plagioclase, in the nature of its augite, especially of its skeleton crystal, in its abounding in apatite, and also in the nature of its ground-mass. But on the other hand it was different in every respect from the agglomeratic andesite of Kita-Iwôjima.

Disappearance of the New Island.—On the 16th of June, we sailed toward the point where the new volcano was said to have lain, but to our wonder and disappointment nothing of the island came in sight. At two in the afternoon, when our steamer at last proceeded to a spot 5 nautical miles distant from Minami-Iwôjima, Captain Nielsen discovered at a great distance something like the white crest of an angry wave dashing against a reef. As we drew near, an island became

visible by aid of a telescope. It looked like the back of a whale half hidden by the waves, and we were given to understand that the new-born island which had been reported to be 480 feet high was now reduced to a low reef of less than 10 feet high (Fig. 2, 3, Pl. IV.).

The Captain, calculating the position and size of the sinking island at 3 nautical miles N.N.W. thereof, found that it was situated $24^{\circ} 16' 30''$ north latitude and $141^{\circ} 30'$ east longitude, and 3 nautical miles north-east of the coast of Minami-Iwôjima, and that it was 8 to 10 feet high and 1500 feet long (Fig. 2, Pl. IV).¹⁾ When seen from the west at the same distance, the island lessened in length nearly one third (Fig. 3, Pl. IV), from which we may infer that the present island is elliptical, somewhat longer east and west. This shape corresponded to that of the former head of the island described in the explorers' report, and reminded us of its form of half an year before. This is a noteworthy fact since it will prove a help to us in considering the cause of the disappearance of the island.

The explorers' report says it was on the 5th of December 1904, that the New Island was first discovered by the inhabitants of Iwôjima, and it was on the 1st of February 1905, that an exploration and survey was effected by them. Thus we see that during the one-hundred and thirty-six days following the latter date (Feb. 1st), a volcanic island, 480 ft. high and 3 miles in circumference, was demolished almost to nothing. The speediness of its demolition is really beyond conception. What is more, some of the inhabitants of Iwôjima told us that they had already lost sight of the New Island in May. If that was really the case, the island was even more short-lived.

Now, there are three chief actions to be considered as the causes of the extinction of volcanic islands; namely, the action of the waves, its own explosion and depression of the volcanic body. Of these three, the first is known to have not infrequently brought about a phenomenon of this sort up to the present day. Graham's Island or Isola Ferdinanda in the Mediterranean Sea, and Falcon Island and Metis

1) My sextant measurement, however, set its length at less than 500 feet.

Island in the Pacific Ocean furnish remarkable instances. These islands were, however, nothing but accumulations of very loose cinders ejected during their own eruptions, and no wonder that they should have been affected by the waves so soon. Yet, Falcon Island (2 miles long and 250 feet high, heaved up in October 1885 and submerged in 1897) which was similar to the New Island in shape and size, vanished after 12 years, and Metis Island (150 feet high and created in 1875) still smaller as it was, passed away in no less than 24 years. There has been no island so short-lived as the New Island. However, it is not to be supposed that the New Island was composed of more fragile substances than the said two islands; and this consideration will naturally dispose us to think that the speedy extinction of the island in question cannot properly be ascribed to the bare action of the waves.

Then the question arises, is it attributable to the explosive action of the volcano? As was the case with Bandaizan and Krakatoa volcano, this action has often demolished a huge mass of mountain with inconceivable force and suddenness; and it may seem to be the very explanation for the present question. But further consideration will make it clear that this is far from being the case since there is not a single proof of the island being subjected to such explosion, and if there had been any such terrible eruption at all, the inhabitants of Iwôjima who witnessed the rising of the New Island would certainly have taken notice of it, and even if dense clouds or fogs prevented the sight, they must have heard the thunderous noise of the explosion or felt shocks of earthquake. Another point that demands our notice is that that part of the island which remained above the sea, as we saw it, was almost of the same shape as is described in the islanders' report, which fact seems to prove that the island kept the same shape until its submergence, scarcely experiencing any considerable explosion. Mr. Satô, one of my fellow-explorers, being told in the Bonin Islands that three weak earthquakes were felt at that island on the 12th of April, 9th and 21st of May respectively, and a strange noise like a distant gun was often heard from the west on the 18th of May, sus-

pected that these phenomena might have had some connection with a supposed explosion of the island. But I am not inclined to agree with him, because, if an earthquake had occurred at the island, it is not to be supposed that it should not have been felt in the Middle and North Sulphur Islands only 30 or 70 nautical miles distant from the New Island, but in the Bonin Islands only which is so much as 200 nautical miles therefrom. The above conjecture will sound even more absurd when we reflect that he must have meant a volcanic earthquake, which is as a rule comparatively small in extent, and that he supposed it to have taken place in a new volcano which belongs to the same zone as the Middle and North Sulphur Islands. From these considerations, it is safe to say that the earthquakes felt in the Bonin Islands had nothing to do with the New Island, but were special ones occurring in the vicinity. Thus, there is not a single fact that proves any explosion in the New Island in connection with its disappearance.

Lastly, the action of depression demands our consideration. When a great mass is poured forth in volcanic eruption, the result will follow that density in that part will become lessened and the pressure will consequently decrease; then it is quite possible that the whole or part of the volcanic body may fall down by its own weight. It is said that large craters such as those of Aso and Hakone, are produced by the depression of part of the crater. According to Mr. Iki,¹⁾ the extension of the crater of Aso now unparalleled in dimension is ascribable to the outflow of an immense mass of "Aso-lava," which, he thinks, caused a depression of the vent. If this is true, it may safely be said that the fall of a crater wall is possible in submarine volcanoes as well as terrestrial. The only difference is this, that since in the case of a terrestrial volcano there is no unerring standard with which to compare its fluctuation, little or no attention is paid; while in the case of marine volcanoes sea-level serves as an unmistakable standard.

In short, although I have no absolute proof or datum to demon-

1) *Geology of Aso Volcano*, by T. Iki. Reports of the Imperial Earthquake Investigation Committee in the Japanese Language. No. 33.

strate the vanishing of the New Island, having found no opportunity to make any personal exploration of it, I think I may safely ascribe the phenomenon to the action of the waves, of which we have so many instances. Nevertheless, I rather hesitate to say this was the only cause of its submergence, considering its exceptional rapidity; and if there was any cause besides the action of the waves, it must be either explosion or depression; but since in this case there is no proof of explosion, the occurrence of which would naturally have attracted the attention of the people in Iwôjima, I venture to say that the phenomenon in question was due to a depression of the volcanic body (which is in most cases apt to escape our notice) as well as the action of the waves.

SUMMARIES.

1. Considering both its geographic position and the nature of its ejecta, it is clear that the New Island was a volcano belonging to the same volcanic line as the other three principal volcanic islands of the Iwôjima group.

2. The eruption was no doubt explosive, and ejected, most of all, the fine débris of pumice at the first stage of eruption, but afterwards vitrophyric lava composed half of obsidian and half of pumice. And though it is certain that other substances composed the body of the island, it remains doubtful whether they were subaerial ashes loosely accumulated or tuffs previously consolidated at the sea-bottom before the eruption; the latter being the case with Motoyama in Iwôjima. Pumice fragments transformed from lava came drifting to the shore of the island and formed a gravel-beach, 120 or 180 feet wide.

3. Petrographically the lava is of olivine-augite-andesite. It greatly resembles, as a whole, the glassy lava of Mt. Pipa in Iwôjima, and widely differs from the agglomeratic lava in Kita-Iwôjima.

4. In point of materials and structures, as Peel Island and Hillsborough Island in the Bonin group are of two different volcanic types, so the volcanic islands of the Iwôjima group may be divided into two

different types. To speak more concretely, Minami-Iwôjima and Kita-Iwôjima (San Augustino Is. and San Alessandro Is. respectively) which became inactive long ago, are composed of the same kind of agglomeratic rock of Hillsborough Island type, are very similar in mountain shapes, and seem to belong to one volcanic type peculiarly their own. On the contrary, Mt. Pipe, Motoyama, the New Island and the submarine volcano in the neighborhood of Kita-Iwôjima, which are all still active and explosive, eject chiefly glassy ashes and rarely vitrophyric lavas but never to such an extent as to augment themselves. Mt. Pipe alone, however, poured forth a comparatively great quantity of lava, so as to assume a conic shape. These four volcanoes are of the other type.

5. On the 1st of February 1905, the New Island was 3 miles in circumference, 200 acres in area, and about 480 feet in height; but, on the 16th of June of the same year, that is, only 136 days after the above-given date, it was reduced to a low reef, only 1500 feet long and less than 10 feet high. The causes of its subsidence remain uncertain, but the chief of them seems to be the encroaching action of the waves. But what brought its submergence so soon? That is the question. It may be that the aforesaid agency was accompanied by a depression of the crater rim.

According to Mr. Hagiwara, Captain of the *Hyôgomaru* which sailed about the adjoining sea of Minami-Iwôjima in the course of June of the present year, the New Island was entirely buried in the sea, and though he inspected the spot where the island had once lain and also its neighborhood, he saw nothing unusual in the condition of the waves. This leaves no room for doubt that the island was but ephemeral as we had expected and that it had sunk down to the depth of more than 10 feet below the surface of the sea.

TOKYO IMP. UNIV.

Nov., 1906.

T. WAKIMIZU.

APPENDIX.

*Eruption of a Submarine Volcano
Near the Bayonnaise Rocks.*

As I have stated in the present paper proper, I was shown the pumice blocks that had come drifting to the Bonin Islands for some time past and found that they are of several different kinds. I was disposed to think that there might have been eruptions of some unknown submarine volcanoes near the "Fuji volcanic zone"; and I found afterwards that I had not been mistaken in this consideration or rather surmise, for I got a report from the crew of the *Okinawamaru*,¹⁾ who chanced to be at work near the scene, to the effect that on the 14th April of last year there was a great eruption of a submarine volcano near the Bayonnaise Rocks,²⁾ an isolated islet in the sea between Aogashima and Smith Rock. A description of the eruption which is said to have been given by Mr. Kajiura, Engineer of the Department of Communications, who was on board the ship, runs as follows:

"The men in the *Okinawamaru* while working near 31° 59' north latitude and 140° 7' east longitude on the 14th of April last year, about 11 o'clock a.m., saw a huge volume of white smoke rising up near the Bayonnaise Rocks, at a spot less than 10 nautical miles distant to the S. S. E.—that is, about 20 ri southeast of Aogashima. By the rough measurement of the crew, the pillar of smoke seemed to be more than 300 feet in diameter and to range from 400 feet to 1000 feet in height, according to the power of the wind and the eruption. The grand spectacle presented by the continuous ejection of white vapor was absolutely beyond the power of pen or tongue to describe. The rocks in front were entirely hidden from view by smoke,

1) *Okinawamaru* is a submarine-cable vessel belonging to the Department of Communications.

2) The Bayonnaise Rocks consist of three big rocks and many small reefs, all of pointed conical shape, of which the highest is less than 30 ft. above the sea-level.

except at short abatements of ejection. Smoke did not cease arising till the *Okinawamaru* left there the following day. There was no knowing when the eruption had begun; but, as the phenomenon was not noticed on the 4th, it probably began abruptly after that day. I regret that we could not approach it, as our duty called us in a different direction, but I saw pumice rising in a great quantity from the spot of eruption and floating eastward with the current. It covered the sea to the breadth of nearly two miles, looking like a large sheet of white cloth spread, or like innumerable white foams floating."

The collected samples of the above-mentioned pumice was put at my disposal through the kindness of Prof. Kotô. They are all of pure white colour, less than one centimeter in diameter, and contain black augite and transparent colourless feldspar as phenocryst. Microscopic examination of thin sections shows that their air-vesicles are not long and flat as in common pumice, but elliptical pores ranged side by side, and what is most remarkable and curious is that some larger and longer vesicles are ranged radially round phenocrysts of feldspar and augite (Fig. 4, Pl. X). This peculiar arrangement of vesicles may be explained by the following consideration:—

It is obvious that the pumice in question is basic, considering that its phenocrysts are all of basic minerals like bytownite and hypersthene as stated below, and that magnetite is contained in a comparatively large quantity. It is generally accepted that basic magma is viscous and is slower in cooling and consolidation than acid magma; but, no doubt, as the magma was ejected into the sea-water, a better conductor of heat than the atmosphere, it was naturally cooled and consolidated in less time than in the atmosphere in spite of its being basic, and was turned in to spongy pumice. Now, this magma contained phenocrysts already crystallized and as it undoubtedly emitted latent heat as it grew cool, a small part surrounding the crystal kept some heat and was in a semi-fluid condition even after the other part became consolidated. Thus we see the cooling and consolidation of this small part was completed a moment later than the others; and while this

was going on, the air-bubbles of a comparatively small number contained therein being stretched by the attraction passing between the central phenocryst and the surrounding walls, assumed the present tubular form and ranged themselves radially. I must confess that this explanation is not quite satisfactory even to myself and further study is necessary for the complete solution of the problem.

As porphyritic ingredients, augite, feldspar and magnetite occur in idiomorphic crystals, each less than 1.5 mm. The feldspars are fresh and transparent, and have but a few inclosures of colourless glass in the shape of negative crystals and acicular crystals of apatite; and zonal structure may be recognized by its manner of extinction. Carlsbad twin is frequent but albite twin is rare. The extinction angle on *oP* face is about -24° . Perhaps the feldspars are of bytownite. The augites belong to the rhombic family and occur in prismatic crystals. They are strongly pleochroic and vary in colour between a greenish yellow, b yellowish brown and c olive-green. Perhaps they are of hypersthene. Feldspar and augite are often combined into aggregate, together with magnetite. In respect to the quantity of phenocryst, feldspar comes foremost, then augite and then magnetite. Besides, there are non-transparent masses which appear to be absorbed residue of some minerals. They are surrounded by radially arranged vesicles as in the case of phenocrysts of feldspar and augite.

Thus, microscopic examination shows us that this rock is hypersthene-andesite. Last of all, let me add that this pumice quite differs from that of the New Island from the petrographical point of view.

PLATE I.

The Geographical Position of Iwôjima (Sulphur Is.) Group.

Plate I.

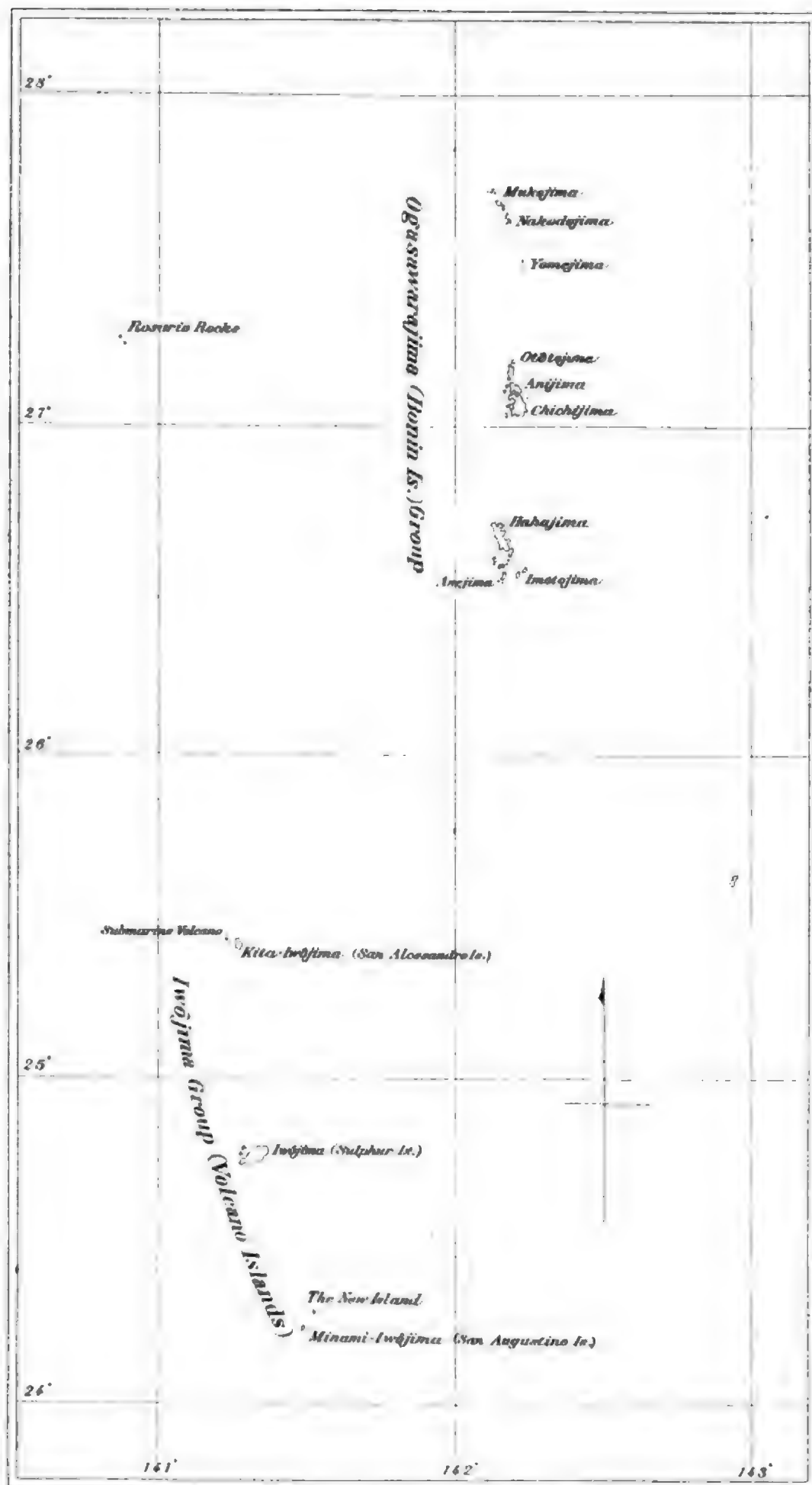


PLATE II.

Kita-Iwôjima (San Alessandro Is.)

Fig. 1.

Map of Kita-Iwōjima

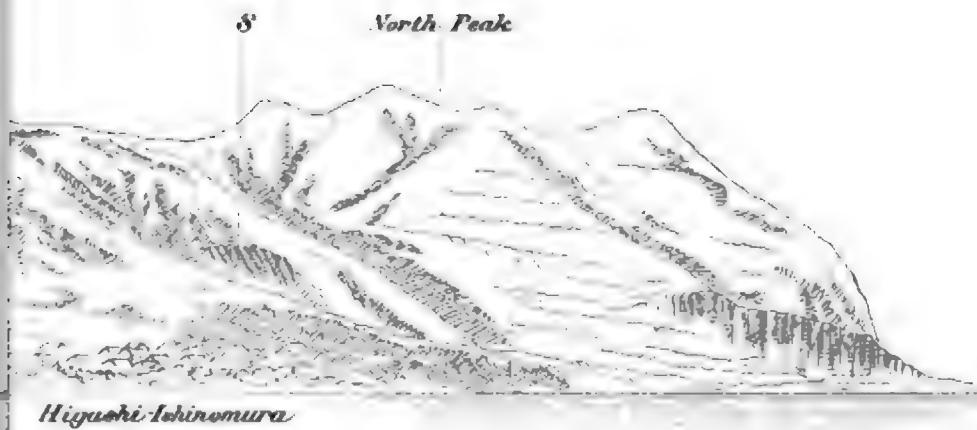
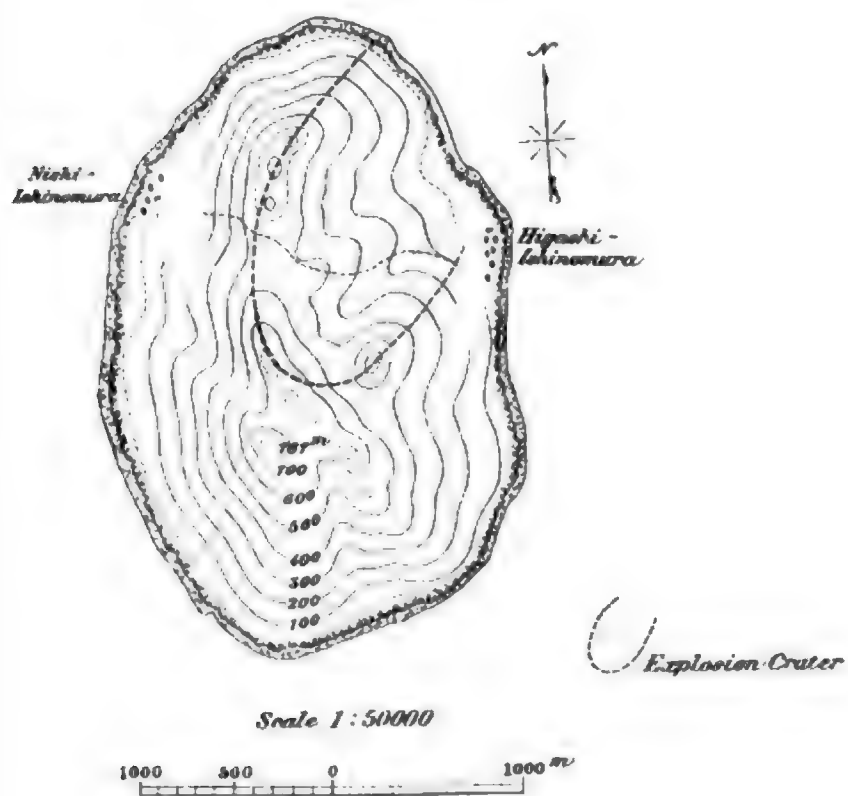


PLATE III.

Iwôjima (Sulphur Is.) or Naka-Iwôjima.

Fig. 1.

Map of Iwōjima

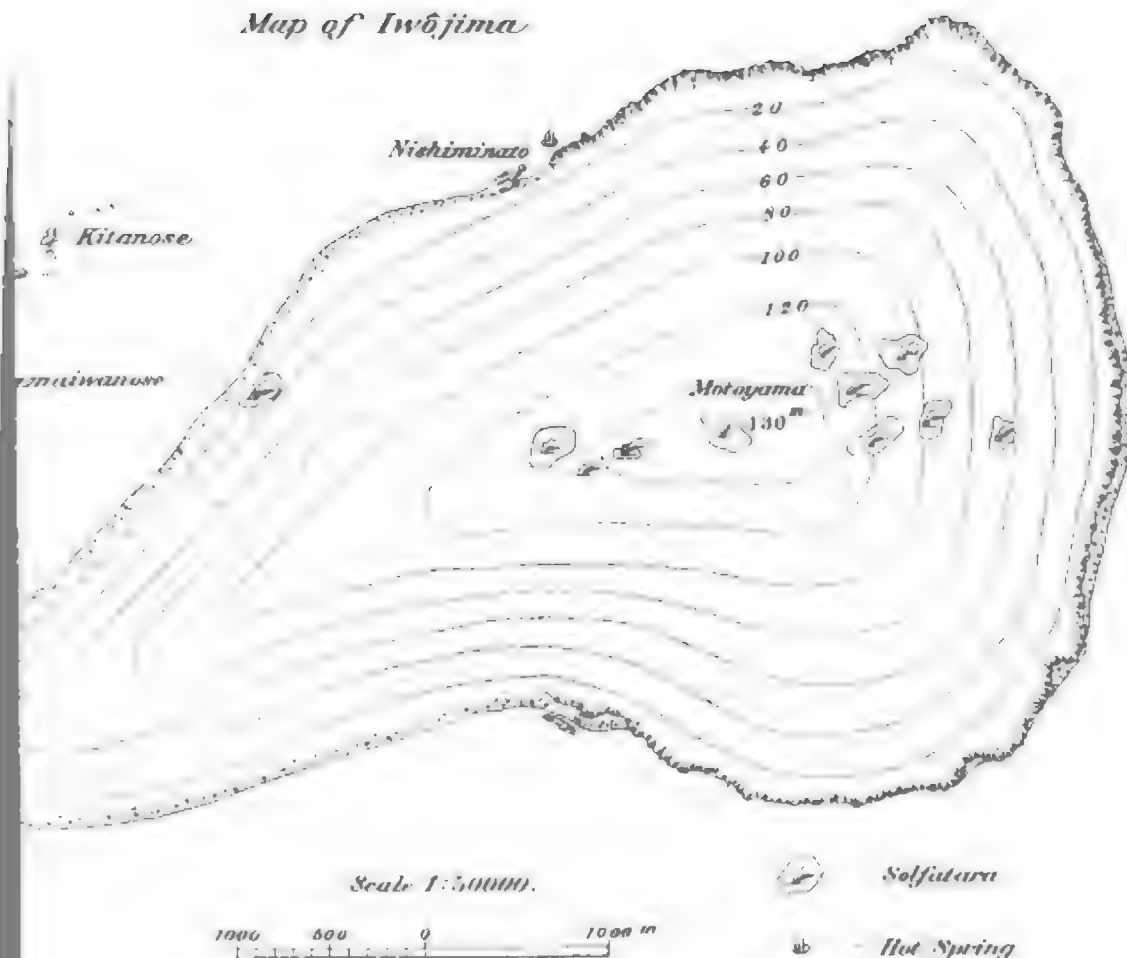


PLATE IV.

Minami-Iwôjima (San Augustino Is.) and the New Island.

PLATE V.

**Fig. 1. Kita-Iwôjima (San Alessandro Is.). N.N.W. 3 Miles
(Naut.). Photographed by the Writer in June 16th, 1905.**

**Fig. 2. Minami-Iwôjima (San Augustino Is.). S.E. 2 Miles
(Naut.). Photographed by the Writer in June 16th, 1905.**



PLATE VI.

Fig. 1. Coral Reefs on the Summit of Motoyama in Iwôjima.
Solfatara on the Left.

Fig. 2. "Tischstein" and Wave-worn Terraces in Iwôjima.



PLATE VII.

Fig. 1. Reef-forming Coral (*Stylophora* sp.) with Black Coating on the Summit of Motoyama in Iwôjima.

Fig. 2. Ditto with Bleached Surface.



PLATE VIII.

Plate VIII.

A block of the lava of the New Island, investigated by the author. This block is pumiceous in the upper part, and gradually passes into obsidian in the lower part. About $\frac{7}{10}$ times of the natural size.



PLATE IX.

Plate IX.

Fig. 1. Obsidian (Olivine-augite-andesite) of the New Island. $\times 16$.

An irregular octagon on the left-hand side of the figure is the section of monoclinic augite, cut near oP. Prismatic cleavage is distinct. The periphery is fringed by augite-microlites and other minute opaque substances. A cubic colourless crystal on the right side opposite to the one mentioned above, is plagioclase (oligoclase). It contains brown glass as inclosures crowding the centre. Rod-like individualized substances universally scattered through the ground-mass, are of microlites of light yellow monoclinic augite.

Fig. 2. Ditto, much more magnified. $\times 147$.

Cross section of monoclinic augite in the centre. Among the augite-microlites in the ground-mass, some penetration twins of stellate form are seen.

Fig. 3. Agglomerate-forming augite-andesite in Kita-Iwôjima. $\times 50$.

The colourless rectangular phenocrysts seen in abundance are of plagioclase (anorthite). The rhombic crystal at the centre is of altered monoclinic augite. The ground-mass is holocrystalline, and is composed of lath-shaped plagioclase, augite grains and magnetite granules.

Fig. 4. Dyke augite-andesite in Kita-Iwôjima. $\times 50$.

The large colourless phenocryst of tabular form is plagioclase that contains abundant glass-inclosures. The ground-mass is holocrystalline, consisting of microlites of feldspar, augite and magnetite, together with a few glass bases.



PLATE X.

Plate X.

Fig. 1, 2. Monoclinic augite in the pumice of the New Island, separated by Thoulet's solution. $\times 50$.

Crystals are well defined. In Fig. 2., a crystal is twinned on $\alpha\bar{P}\alpha$.

Fig. 3. Brachypinacoidal section of oligoclase in the pumice of the New Island. $\times$ ca. 30.

Take notice of the development of basal cleavage and zonal arrangement of glass-inclosures.

Fig. 4. Section of the pumice ejected by a submarine volcano near the Bayonnaise Rocks. $\times 50$.

This figure shows the radial divergent arrangement of air-vesicles around a well-defined feldspar-phenocryst.



PLATE XI.

Plate XI.

Fig. 1. Apatite crystals in Motoyama-tuff of Naka-Iwôjima.

They contain remarkable glass-inclosures, elongated in the direction of the principal axis. Most of the inclosures possess one or more immovable air-bubbles.

Fig. 2. Apatite crystals in the pumice of the New Island.

Compare them with those in the preceding figure.

Fig. 3, 4, 5, 6. Well-defined crystals of monoclinic augite in the pumice of the New Island.

$s = -P$, $b = \alpha\bar{P}\alpha$, $m = \alpha P$, $n = \alpha\bar{P}\alpha$.

Fig. 7. Twin-crystal of ditto. Twinned on $\alpha\bar{P}\alpha$. This figure also shows the mode of occurrence of apatite- and glass-inclosures in the crystal.

Apatite needles and elongated glass-inclosures are so placed that their longitudinal axes lie parallel to some domal faces of the crystal.

Plate XI.

6



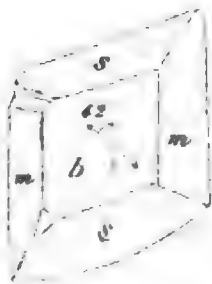
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5



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3



7



2



PLATE XII.

Plate XII.

Fig. 1. Olivine in the pumice of the New Island.

The crystal is considerably corroded, and sometimes intruded by ground-mass.

Fig. 2. A basal section of oligoclase in the pumice of the New Island.

Apatite needles and coloured glass-inclosures are abundantly enclosed.

Fig. 3. Some of the glass-inclosures in ditto.

The edge of the inclosures in part runs parallel to some crystal faces of the encloser; they are thinly flattened along the cleavage faces of the latter.

Fig. 4. Colourless hexagonal scales of muscovite (?) coating the face of orthoclase in Motoyama-tuff as the decomposition product of the latter.

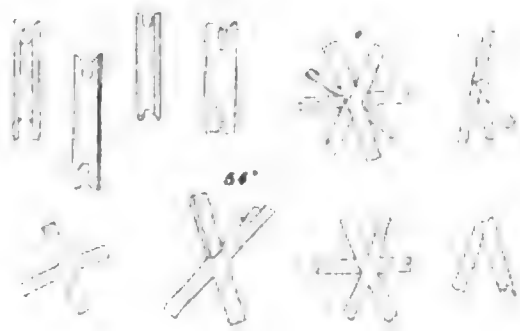
Fig. 5. Microlites of monoclinic augite (greatly magnified) scattered in the ground-mass of the obsidian of the New Island. Both extremities of prisms are commonly indented or irregularly truncated. They are often twinned in various manners, as shown in the figure.

Fig. 6. A peculiar crystal of monoclinic augite in the obsidian of the New Island. The two diagonals connecting opposite angles mark a well-developed shining face, while the remaining part of the crystal face is slightly grooved and of dull lustre.

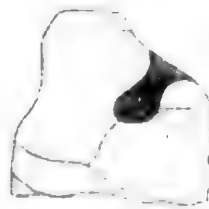
Fig. 7. Skeleton crystal of augite in the glassy augite-andesite of Mt. Pipe, Naka-Iwôjima, described by Dr. Petersen. (This is a original figure of Dr. Petersen.) Note its near resemblance to the preceding.

Plate XII.

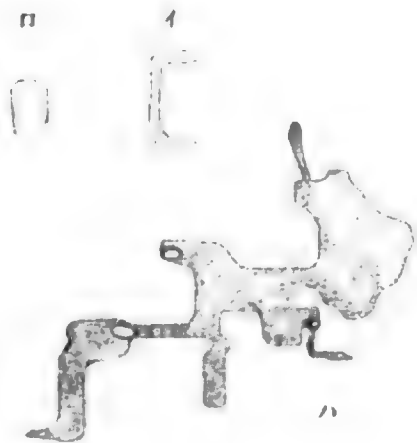
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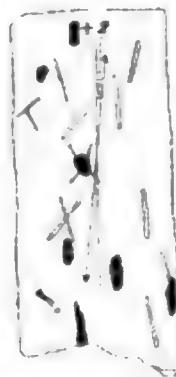
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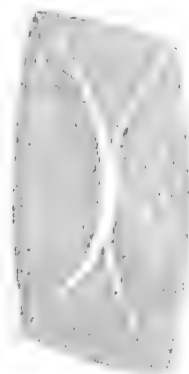
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No. 23

Report on the Great Indian Earthquake of 1905.
Part I: Seismograms.

TŌKYŌ, 1907.

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PREFACE.

Immediately after the disastrous earthquake of April 4, 1905, the author proceeded to India, by order of the Imperial Government, to study the seismic phenomena, arriving at Simla on May 30, and spending $2\frac{1}{2}$ months in visiting different places in the shaken area.

The present Number of the *Publications*, constituting Part I of the Report on the Indian Earthquake, contains a collection of the more typical seismograms obtained at various seismological stations, on the occasion of the catastrophe, which caused a loss of 20,000 human lives. For the sake of convenience of printing, the descriptions of the different seismograms, and the discussions of the transit velocities, vibration periods, etc., are given, as Part II of the Report, in No. 24 of the *Publications*; the first two parts together giving the results of the seismographic observations of the great disturbance in question. Part III contains a general account of the earthquake.

One of the objects in issuing Parts I and II of the Report is to prepare a systematized account of the instrumental observations of the great earthquake, which I have specially studied, to be laid, for discussion, before the learned members of the General Conference of the International Seismological Association to be held in September next at the Hague. I am aware that in this attempt I have fulfilled my task by no means satisfactorily, and will consider myself highly successful if the results of my analysis prove of use to seismologists for the researches on the physics of the earth's crust.

F. OMORI.

March, 1907.

Seismological Institute, Tokyo.

REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

PART I: SEISMOGRAMS.

By

F. OMORI, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

1. *Introductory.* The earthquake of April 4, 1905, in the north-western part of India, was a very large disturbance, and caused a loss of human lives, whose number was surpassed by no other destructive seismic shock in the modern times. This catastrophe, generally known as the Kangra Earthquake, and the great Assam and Bengal earthquake of June 12, 1897, were probably caused by the stress in the earth-crust which is connected with the curvilinear form of the Himalayas. As India is visited by severe earthquakes from time to time, it is to be greatly desired that precautions should be taken in the construction of houses so as to mitigate the seismic damage to life and property.

The misfortune which had befallen the people of British India deeply touched the Japanese. On receipt of the news of the catastrophe His Imperial Japanese Majesty at once sent a message of sympathy to His Britannic Majesty. The mayor of Tokyo also dispatched a telegram of condolence to King Edward, while the War Minister addressed to the Viceroy of India a telegraphic message expressing his deep sympathy and sorrow for the fatal calamity that had befallen Indian soldiers at Dharmasala. The *Jiji-Shinpo*, a leading daily newspaper, editorially commented on

the seismic disaster and at once opened a subscription for the benefit of the victims of the earthquake.

2. Note on the Character of Earthquake Motion. The earthquake motion, especially that due to a great disturbance, is by no means simple in character, but consists of different sets of vibrations, whose period varies between a fraction of a second to over 1 minute. The quickest tremors, which I have ever observed, was in the case of one of the after-shocks of the great Mino-Owari (Japan) earthquake of Oct. 28, 1891, registered at the temporary seismological observatory set up in the village of Midori in the Néo-Valley, the most central part of the meizoseismal zone, its complete period being only 0.023 sec. On the other hand, the longest period of vibration, which I have so far observed, was 86 sec. and occurred in the EW component diagram of the Kangra Earthquake obtained at Tokyo. It is quite probable that, in the case of a great seismic disturbance, there exist still slower vibrations, of period, say, of several minutes, or of even over 1 hour; the different seismographs in use at present recording only the quicker components of the earthquake motion.

The periods of vibration at a given place seem in the case of the *macro* or *sensible* earthquake motion to remain nearly constant for different earthquakes;* the same conclusion also being probably true of the *micro* or *insensible* earthquake motion of pulsatory nature, or that consisting of slow-period vibrations.†

Further, for the latter case, the principal periods seem to remain essentially the same for different places all over the earth. These facts would seem to point out that the whole earth's crust is making slow small vibrations with definite periods, whose am-

* The *Publications*, No. 11.

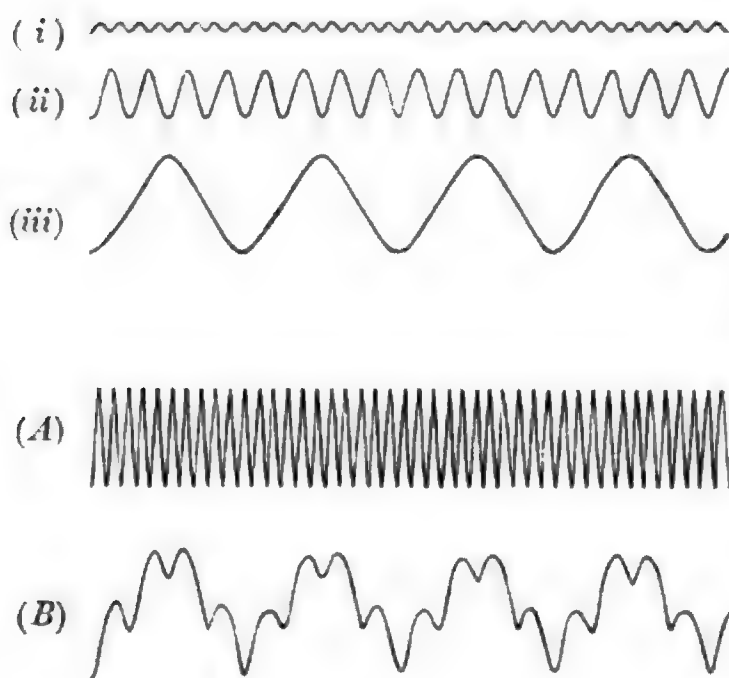
† The *Publications*, Nos. 5 and 13, also the *Bullet'n*, Vol. I, No. 2.

plitudes become enlarged at the time of a great earthquake shock, just as the waters of a given portion of a sea are thrown, by great sub-marine earthquakes and volcanic eruptions, or by atmospheric depressions, into destructive tidal disturbances, whose periods are the same as those of the waves existing at ordinary times and are constant at each given sea-coast. Slow vibrations generally appear in earthquakes which are sufficiently great, and the supposition held by some seismologists that long-period movements are to be observed only at a great distance from the seismic centre is evidently untrue; slow vibrations of period over 30 or 60 sec. having been observed in Tokyo on the occasion of some earthquakes, which originated off the southern and eastern coasts of Japan. The fact is probably that the different sets of slow and quick movements are generated simultaneously at the earthquake centre, but the vibrations of shorter periods are, in their radial propagation, reduced in amplitude much more quickly than those of slower periods, due to the viscosity of the material forming the earth's crust; the result being that the vibrations of the macroseismic nature exist only slightly in the earthquake motion due to a distant source, while the movements of different slow periods become successively prominent at the varying radial distances.*

3. *Telesismic Motion and Instrumental Record.* From what has been said in the preceding §, it will be readily understood that, in the telesismic disturbance due to a large source, slow vibrations play an important part; the division of the motion into the different phases or sections depending, in the first place, on the amplitude of the constituent vibrations. From this point of view, a standard seismograph must be one of long period.

* The *Publications*, No. 21, p. 80.

As the intensity, or maximum acceleration, of the earthquake motion is proportional to the amplitude, but varies in the ratio of the inverse square of the period, the friction at the junction of the



“steady axis” of a mechanically registering seismograph and the recording pointer, and that between the latter and the record-receiving surface, will interfere very much with the accuracy of the result. For example, a vibration of 40 seconds period will be affected by the friction 100 times more than an-

other of equal size, whose period is 4 sec. Further, to correctly record a vibration the natural oscillation period of the “steady mass” must be much longer than that of the latter. Hence the real range (double amplitude) of motion of a very slow period, say, of over 40 seconds, would be always larger than indicated on the record furnished even by long-period seismographs in use at present; the consequence being that the records from different seismographs differ considerably from each other, according, amongst others, to the proper oscillation period of the latter. Thus, let the earthquake motion be composed, for simplicity's sake, of three sets of vibrations, (i), (ii), and (iii) whose periods are, for example, 4, 8, and 32 seconds, respectively. If, now, the

natural oscillation period of a seismograph be short, say, not more than 4 seconds or so, and if the multiplication ratio of the recording pointer be large, the seismogram would simply consist in large pendulum oscillations as is diagrammatically represented in (A) slower movements of (ii) and (iii) types being not indicated at all. On the other hand, if the natural pendulum period be sufficiently long, the record will be as is represented in (B), the different sets of vibrations being represented more nearly in their true sizes. In this latter case, however, small quick vibrations of the (i) type will be almost entirely obscured, due to the superposition of large slow movements.

4. Function of Microseismographs. No single seismograph can record clearly all the different sets of the vibrations composing the earthquake motion, when the slow component is of a large amplitude. At least two instruments are required for the complete observation of the horizontal (or vertical) motion: the one, with a long oscillation period of 60 sec. or more, recording the slower component, and the other, with a short period of some 15 seconds, recording the quicker component.

To prolong the oscillation period of a horizontal pendulum, the following three conditions are necessary:—

(1). The weight of the heavy bob must not be too great, as the point of support must always be kept very sharp.

(2). The length of the strut, or the horizontal distance between the point of support and the steady axis, must not be short.

(3). The height of the pendulum, or the vertical distance between the point of support and the point of suspension, must be made large.

With a horizontal pendulum set up in the "Earthquake-proof

House," which is 2.65 meters in height and whose strut was 1 meter in length, the oscillation period was raised to 3 minutes, the weight of the bob being $7\frac{1}{2}$ kg.* By increasing the height and the length in question the oscillation period can of course be more lengthened.

For the observation of the W_2 wave, or the earthquake motion propagated along the major arc between the centre of disturbance and a given station, and the W_3 wave, namely, the repetition of that first propagated along the minor arc, or the shortest path, the friction of the instrument must be made very small, the oscillation period being made suitably long.

5. Seismoscope. Although the primary object of Seismometry is to record correctly or absolutely the earthquake motion, sensitive seismoscopes are also invaluable in the researches on earthquake phenomena, especially, in observing, (*i*), the small movements at the commencement of the 1st preliminary tremor, and, (*ii*), the feeble vibrations of the W_2 and W_3 waves. The instruments best adapted to these two last mentioned purposes would be, respectively, a horizontal pendulum of very small mass and of a high magnification, with an oscillation period of 3 or 4 seconds, and a similar one with an oscillation period of about 20 sec.; the registration being in each case made photographically. Instruments of Professor Milne's type, with proper improvements, would, in this respect, prove very useful.

For the observation with such seismoscopes as above supposed there is no need for damping the motion of the pendulum, the object being to utilize the proper oscillations of the latter. A high magnification instrument with a large amount of friction fails to record satisfactorily the slow small vibrations.

* The *Publications*, No. 5; subsequently the weight of the bob was increased to 46 kg.

6. Observations of the Kangra Earthquake. In response to my circular asking for the copy of the seismographic or magnetographic records of the Kangra Earthquake, photographic or printed reproductions of the diagrams have been sent in from the following stations:—

<i>Japan</i>	Mizusawa, Ōsaka, Kōbe, Tadotsu, Kyōto, Ishinomaki, Miyako.
<i>Formosa</i>	Taihoku, Taichu, Tainan.
<i>India</i>	Dehra Dun, Barrackpore, Colaba (Bombay), Calcutta (Alipore), Kodaikanal (Madras).
<i>China</i>	Shanghai (Zikawei).
<i>Philippines</i>	Manila.
<i>Java</i>	Batavia.
<i>Austria-Hungary</i>	Laibach, Pola, Triest, O'Gyalla.
<i>Italy</i>	Ximeniano, Queree, and Quarto-Castello (Florence), Ischia, Rocca di papa, Padova.
<i>Germany</i>	Potsdam, Strassburg, Göttingen, Leipzig.
<i>Sweden</i>	Upsala.
<i>Great Britain</i>	Shide, Kew, Liverpool (Bidston), Birmingham, Edinburgh, Paisley.
<i>Spain</i>	San Fernando.
<i>Mauritius.</i>	
<i>Cape of Good Hope.</i>	
<i>Canada</i>	Toronto, Victoria, B.C.
<i>The United States</i>	Baltimore, Washington, D. C., Cheltenham.
<i>Mexico</i>	Tacubaya.
<i>Brazil</i>	Rio de Janeiro.
<i>New Zealand</i>	Christchurch, Wellington.

I have here to express my warmest thanks to the seismologists

in charge of these observatories for having so kindly supplied me with the results of their observations.

Besides the places above mentioned, in Tokyo the earthquake was observed at three stations, namely, the Seismological Institute (at Hongō), the branch Observatory of Hitotsubashi, and the Central Meteorological Observatory.

The diagrams obtained at the different seismological observatories have furnished very valuable materials of investigation, each showing, according to the nature of the instrument, its own characteristics. What is specially interesting of these seismograms is that the latter indicate very distinctly the W_2 motion, or the earthquake propagated along the major arc. This motion was in many cases quite large, obscuring by its superposition the W_1 wave, or the repetition of the earthquake proper.

Further, in the discussion of the propagation velocities and the duration of the 1st preliminary tremor, I was enabled to utilize the published results of seismographic observations at the following stations :—

<i>Russian Turkestan</i>	Taschkent.
<i>Siberia</i>	Irkutsk.
<i>Caucasus (Russia)</i>	Tiflis, Achalkalaki, Batum, Borshom, Derbent, Schemacha.
<i>Russia</i>	Jurjew ; Nikolajew.
<i>Samoa</i>	Apia.
<i>Porto Rico</i>	Vieques.
<i>Hawaii</i>	Honolulu.
<i>Syria</i>	Bairut.
<i>Azores</i>	Ponta Delgada.
<i>Servia</i>	Belgrade.
<i>Austro-Hungary</i>	Krakau.

Germany Jena, Hamburg.

Italy Messina.

The number of the stations taken into account was nearly 70, while that of the diagrams I have analyzed was also nearly 70.

7. List of Seismograms. Pls. I to XXII contain 41 more typical seismograms, all reproduced in the original size, except the Quarto-Castello register which has been reduced half size. The following is a list of the different seismograms.

LIST OF FIGURES (PLS. I TO XXII).
SEISMOGRAPHIC RECORDS OF THE GREAT INDIAN
EARTHQUAKE OF APRIL 4, 1905.

PLS. I TO VIII. JAPANESE STATIONS.

Pls. I to VI. Seismological Institute, Imperial University, Hongō, Tōkyō, Japan.

Time of Earthquake Commencement = $0^h 59^m 08^s$.

*Pl. I. Fig. 1. Omori Horizontal Pendulum. EW Component.**
Weight of the bob = 17.4 kg. Multiplication = 15. Pendulum
Period = 61.5 sec.

The letters *a, b, c, d, . . . A, B, C, D, . . . X* denote the vibrations corresponding to those denoted by the same letters in the Ōsaka EW Component Seismogram (Pl. VI).

W_2' is the commencement of the vibrations propagated along the Major Arc, from India to Tokyo, probably corresponding to the approximate beginning of the 2nd phase of the principal portion. W_2 corresponds to some later epoch in the same phase.

* By mistake, the arrow indicating the commencement of the earthquake has been marked about 17 sec. too early.

Pl. II. Fig. 2. Omori Horizontal Pendulum. NS Component. Weight of the bob=46 kg. Multiplication=20. Pendulum Period=48.5 sec.

The numerals 1, 2, 3, 9 denote the vibrations corresponding to those denoted by the same numerals in the Kōbe NS Component Seismogram (Pl. VII).

W'_2 and W_2 correspond respectively to the 1st phase, and some part in the 2nd phase, of the principal portion of the earthquake motion propagated along the Major Arc.

Pl. III. Fig. 3. Gray-Ewing Type Vertical Motion Seismograph, adapted to a continuous registration. Weight of the bob=9 kg. Multiplication=12. Pendulum Period=about 4 sec.

For the sake of convenience of printing, the seismogram has been cut into two, the part (I) being continued to the part (II).

W_2 here corresponds to the commencement of the 3rd phase of the principal portion of the Major Arc propagation.

Pl. IV. Fig. 4. Omori Horizontal Pendulum Tromometer. EW Component. Weight of the bob=49.5 kg. Multiplication=120. Pendulum Period=23 sec.

For the sake of clearness, this figure gives only the record for the first 25 minutes, namely, the part between the commencement of the 1st preliminary tremor and that of the 3rd phase of the principal portion. The commencement of the earthquake is quite sharply defined.

Pl. V. Fig. 5. Omori Horizontal Pendulum Tromometer.

This diagram, which is the continuation of the record in Pl. IV, gives the 3rd and subsequent phases (4th and 5th) of the principal portion, for the 23 minutes between about 1^h 29^m and 1^h 52^m.

Pl. VI. Fig. 6. Meteorological Observatory of Ōsaka, Japan.
Omori Horizontal Pendulum of portable form. EW Component.
Weight of the bob=16 kg. Multiplication=20. Pendulum
Period=28 sec.

Time of EQ. Commencement= $0^h 58^m 51^s$.

The alphabets, *a, b, c, X* correspond to those in the Tokyo EW Component Seismogram (Pl. I). W_2' corresponds to some epoch in the 2nd phase of the principal portion of the Major Arc propagation; W_3 being the earthquake motion, which first travelled along the Minor Arc from India to Ōsaka, proceeded further on, and came back again to the latter place after going completely round the earth.

Pl. VII. Fig. 7. Meteorological Observatory of Kōbe, Japan.
Omori Horizontal Pendulum of portable form. NS Component.
Weight of the bob=11 kg. Multiplication=20. Pendulum
Period=27 sec.

Time of EQ. Commencement= $0^h 58^m 26^s$.

The numerals, 1, 2, 3,9 correspond to those in the Tokyo NS Component Seismogram (Pl. II).

Pl. VIII. Omori Horizontal Pendulums of small multiplication. EW
Component. Weight of the bob=6.5 kg. Multiplication=6.

Time of EQ. Commencement=about $0^h 57^m$.

Fig. 8. Meteorological Observatory of Tainan, (Formosa).
Pendulum Period=17 sec.

Fig. 9. Meteorological Observatory of Taichu, (Formosa).
Pendulum Period=15 sec.

PLS. IX TO XVII. AMERICA, MEXICO, ITALY,
 GERMANY, SWEDEN, BIRMINGHAM, MANILA, COLABA.

(B). *Grande Pendolo Orizzontale Stiattesi*. Mass=500kg. EW Component. Multiplication=25. Pendulum Period=17.4 sec.

(C). *Grande Microsismografo Vicentini a pantografo*. Mass=500 kg. Multiplication=40. Pendulum Period=4.6 sec.

The numerals, 1, 2, 3, 4, 5, and 6, have the same significations as in the 2 preceding Plates.

Pl. XII. Fig. 17. *Royal Geodynamic Observatory of Ischia, Italy.*

Time of EQ. Commencement=0^h 58^m 56^s.

(A). *Porto d'Ischia. Pendoli Orizzontali Grablovitz*. (Improved form) Multiplication=8. Pendulum Period=13.0 sec. (NS); 17.0 sec. (EW).

(B). *Grande Sentinella (Casamicciola). Pendoli Orizzontali Grablovitz*. (Primitive form). Multiplication=8. Pendulum Period=11.3 sec. (NS); 11.0 sec. (EW).

(C). *Porto d'Ischia. Vasca Sismica*. Multiplication=70.

(D). *Grande Sentinella (Casamicciola). Vasca Sismica*. Multiplication=90.

Pl. XIII. Fig. 18. *Royal Geodynamic Observatory of Rocca di Papa (Rome), Italy. Microsismografo Agamemnone*. Mass=500 kg. Multiplication=70. Pendulum Period=4.2 sec. NW-SE and NE-SW Components.

Time of EQ. Commencement=0^h 58^m 51^s.

Fig. 19. *Philippine Weather Bureau, Manila. Vicentini Microseismograph*. Weight of the bob=100 kg. Pendulum Period=2.4 sec. NNW-SSE Component.

Time of EQ. Commencement=0^h 58^m 25^s.

Pl. XIV. Figs. 21 and 22. *Royal Geological Survey Office, Leipzig, Germany. Wiechert's Astatic Pendulum*. Weight of the

bob = 1100 kg. *Indicator-Multiplication* = 250. *Pendulum Period* = 9.2 sec.

{ *Fig. 21.* EW Component.
 { *Fig. 22.* NS „

Time of EQ. Commencement = 0^h 58^m 44^s.

Fig. 20. *Government Observatory, Colaba, Bombay, India.*
Colaba Seismograph. NS Component. Pendulum Period = 27 sec.

Pl. XV A and Pl. XV B. *Geophysical Institute, Göttingen, Germany*
Wiechert's Astatic Horizontal Pendulum. Weight of the bob =
 1200 kg. *Indicator-Multiplication* = 160.

{ *Fig. 23.* NS Component. *Pendulum Period* = 15.7 sec.
 { *Fig. 24.* EW „ „ „ 15.3 „.

Time of EQ. Commencement = 0^h 58^m 55^s.

The original complete diagram has, for the convenience of printing been cut into two halves, so that Pl. XV A is continued to Pl. XV B.

Pl. XVI and Pl. XVII. *Meteorological Institute, Royal University, Upsala, Sweden.* *Wiechert's Astatic Pendulum. Weight of the bob* = 1000 kg. *Indicator-Multiplication* = 235. *Pendulum Period* = about 9 sec.

{ *Fig. 25.* NS Component.
 { *Fig. 26.* EW „

Time of EQ. Commencement = 0^h 58^m 22^s.

Pls. XVIII to XXII. *Milne Horizontal Pendulum Seismograms.*

The Milne Horizontal Pendulums are generally so located that the boom points N-S, recording the EW Component motion.

PLS. XVIII-XIX. BRITISH AND SPANISH STATIONS.

Pl. XVIII. *Fig. 27.* *National Physical Laboratory, Kew Observatory, England.*

Time of EQ. Commencement = $1^h 00^m 12^s$.

Fig. 28. Royal Observatory, Edinburgh, Scotland.

Time of EQ. Commencement = $1^h 00^m 00^s$.

The letters, *a, b, c, d, e, f, g, h, i, j, k, l*, denote the different maximum movements which can be well identified in the Kew and San Fernando Seismograms.

Fig. 29. Slide, Newport, Isle of Wight. C-Instrument, EW Component.

Fig. 30. Slide, Newport, Isle of Wight. B-Instrument, NS Component.

Time of EQ. Commencement = $1^h 01^m 00^s$.

The letters, *a, b, c, d, e, f, g*, in Figs, 29 and 30 denote corresponding movements in the two components.

Pl. XIX. Fig. 31. Liverpool Observatory, Bidston, England.

Time of EQ. Commencement = $1^h 00^m 36^s$.

Fig. 32. The Coats Observatory, Paisley, Scotland.

Time of EQ. Commencement = $1^h 00^m 00^s$.

Fig. 33. Marine Observatory of San Fernando, Spain.

Time of EQ. Commencement = $1^h 02^m 30^s$.

The letters, *a, a', b, b', c, o*, denote the different maximum movements, most of which can be identified in the seismograms obtained at the British Stations, especially, at Kew and Edinburgh. In Figs, 27 to 33, *W*, denote the earthquake motion propagated along the major arc; the variation in the time of its commencement at the different stations being partly due to some dissimilarity of the pendulum periods, and partly to the difference in the epicentral distances.

PL. XX. INDIAN STATIONS.

Fig. 34. Meteorological Observatory of Alipore, Calcutta.

Time of EQ. Commencement = $0^h 52^m 00^s$.

Fig. 35. Government Observatory, Colaba, Bombay.

Time of EQ. Commencement = $0^h 53^m 08^s$.

Fig. 36. Government Observatory, Colaba, Bombay.

The Float and Balance Records of the vertical motion.

PL. XXI. NEW ZEALAND AND CAPE TOWN.

Fig. 37. Magnetic Observatory, Christchurch, New Zealand.

Time of EQ. Commencement = $1^h 10^m 00^s$.

Fig. 38. Wellington, New Zealand.

Time of EQ. Commencement = $1^h 09^m 48^s$.

The Wellington diagram has been cut into two, for the convenience of printing.

In Figs. 37 and 38, the corresponding movements are marked by the letters, *a, b, c, d, x, y, z.*

Fig. 39. Royal Observatory, Cape of Good Hope, South Africa

Time of EQ. Commencement = $1^h 02^m 30^s$.

PL. XXII. CANADIAN STATIONS.

Fig. 40. Victoria, British Columbia.

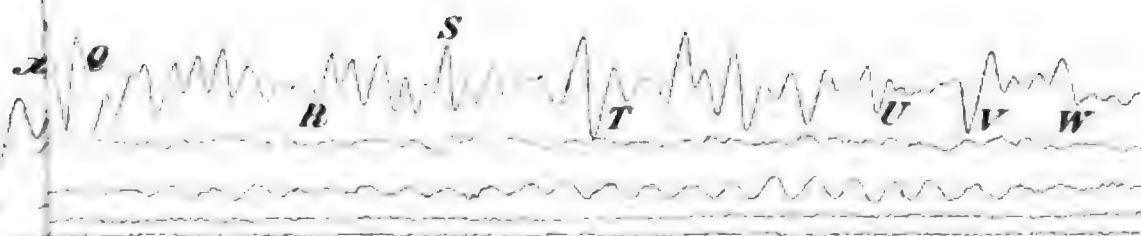
Time of EQ. Commencement = $1^h 06^m 48^s$.

Fig. 41. Toronto Observatory, Ontario.

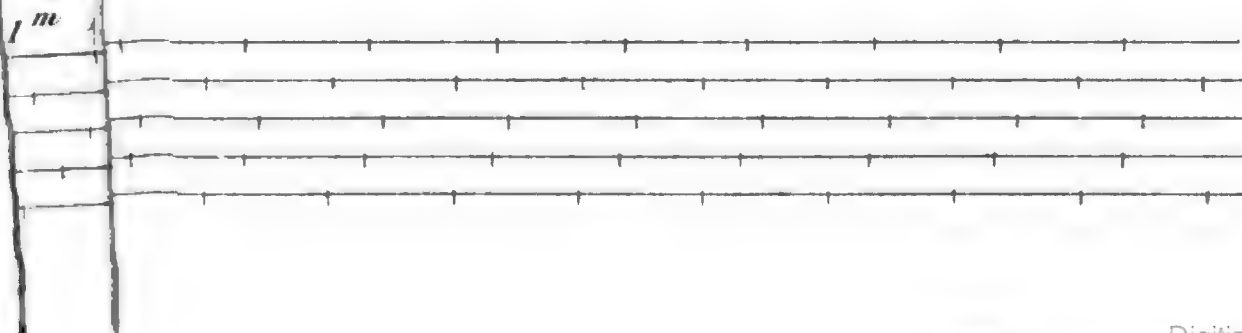
Time of EQ. Commencement = $1^h 06^m 36^s$.

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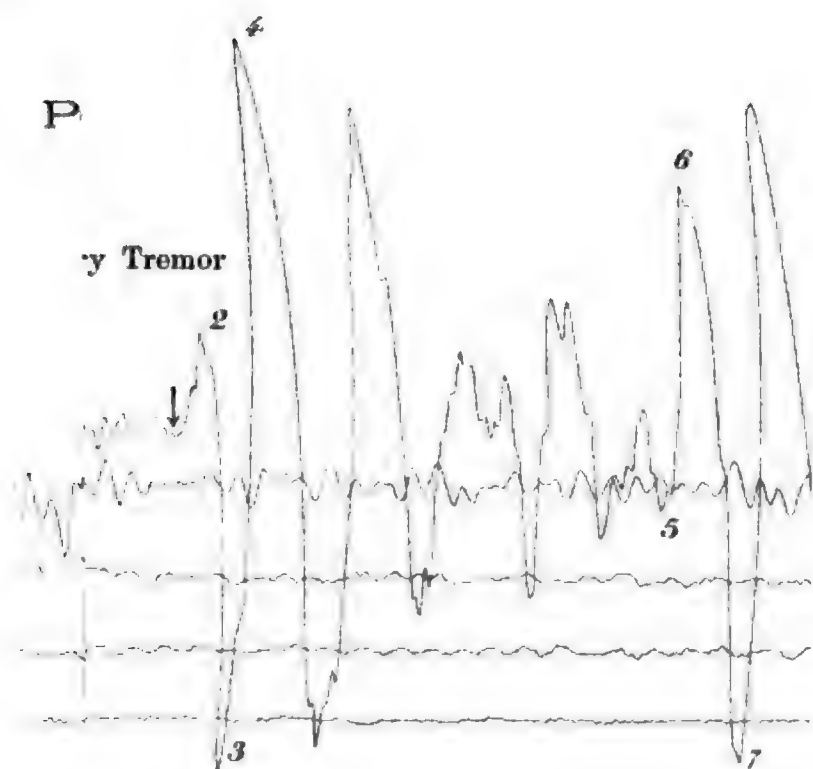
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Vibrations propagated along the Minor Arc,
 along the arcual path between India and Tokyo.
 Moment of the vibrations propagated from
 Adakyo along the Major Arc of the earth;
 according to the 3rd Phase of its Principal
 Porti



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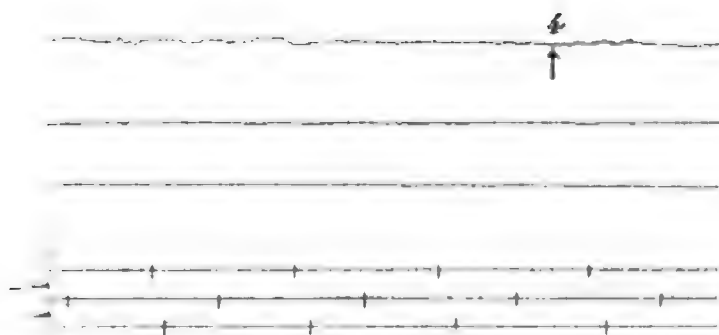


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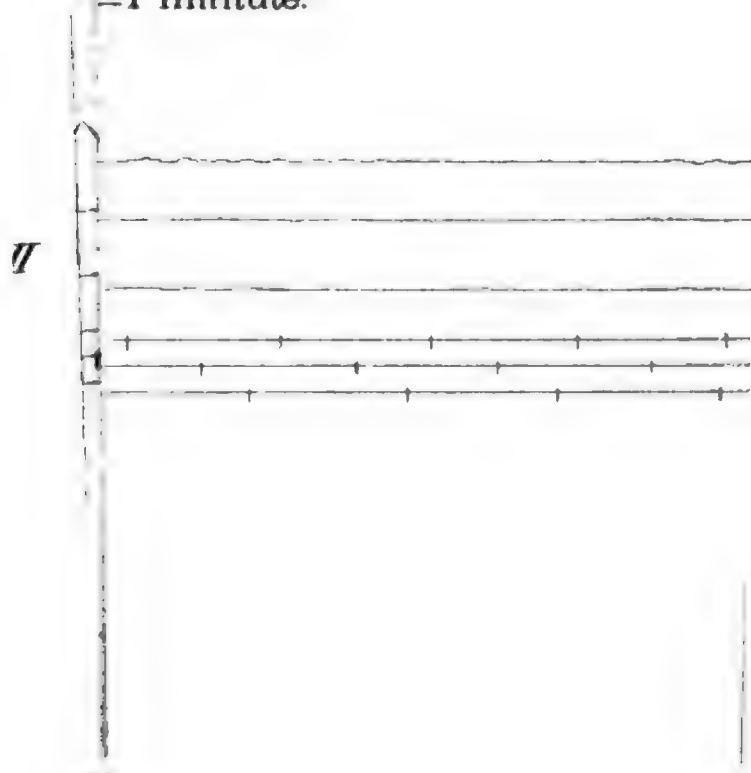


Observed in Tokyo. Seismograph.

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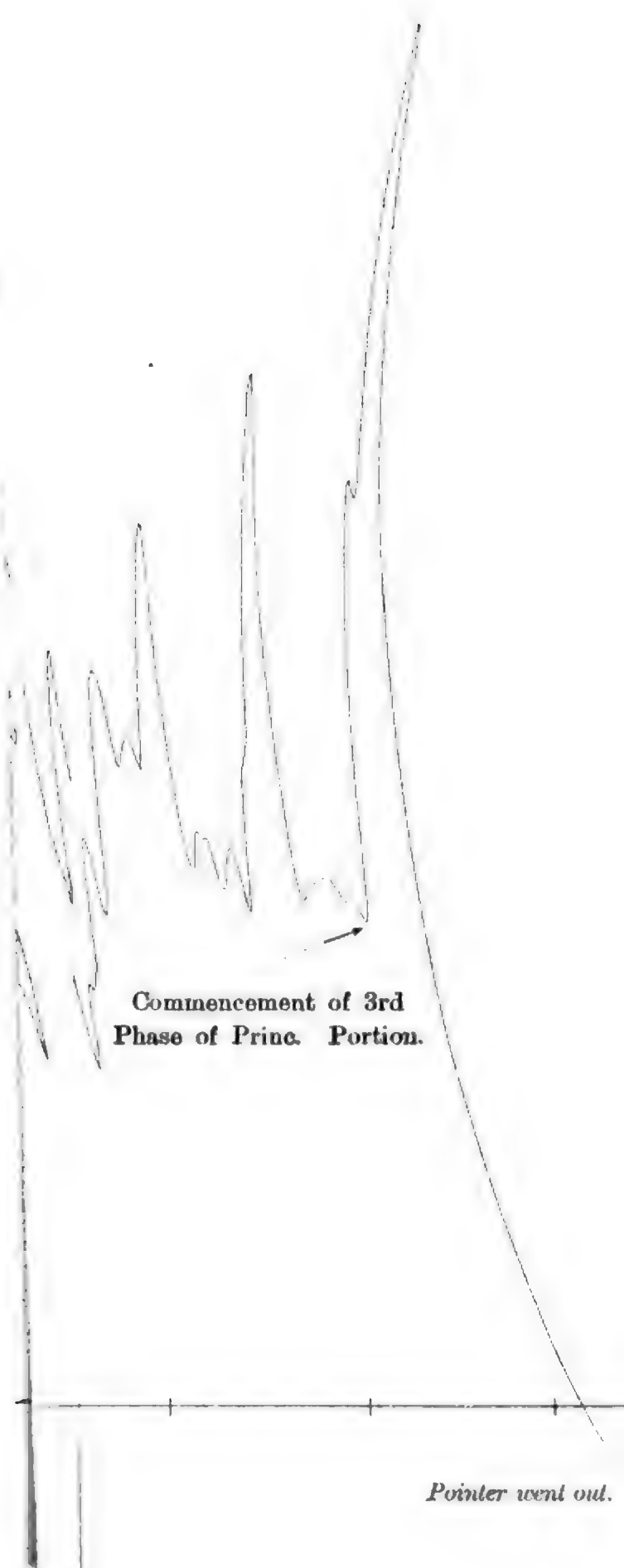


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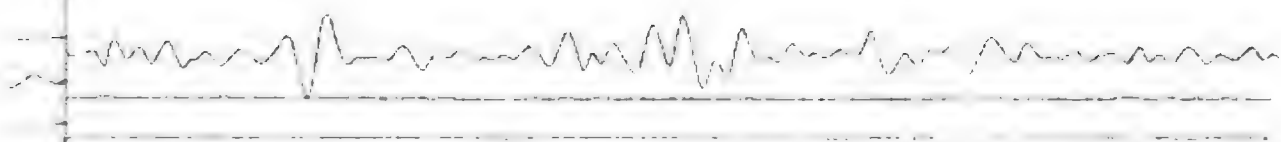
Commencement of 3rd
Phase of Princ. Portion.

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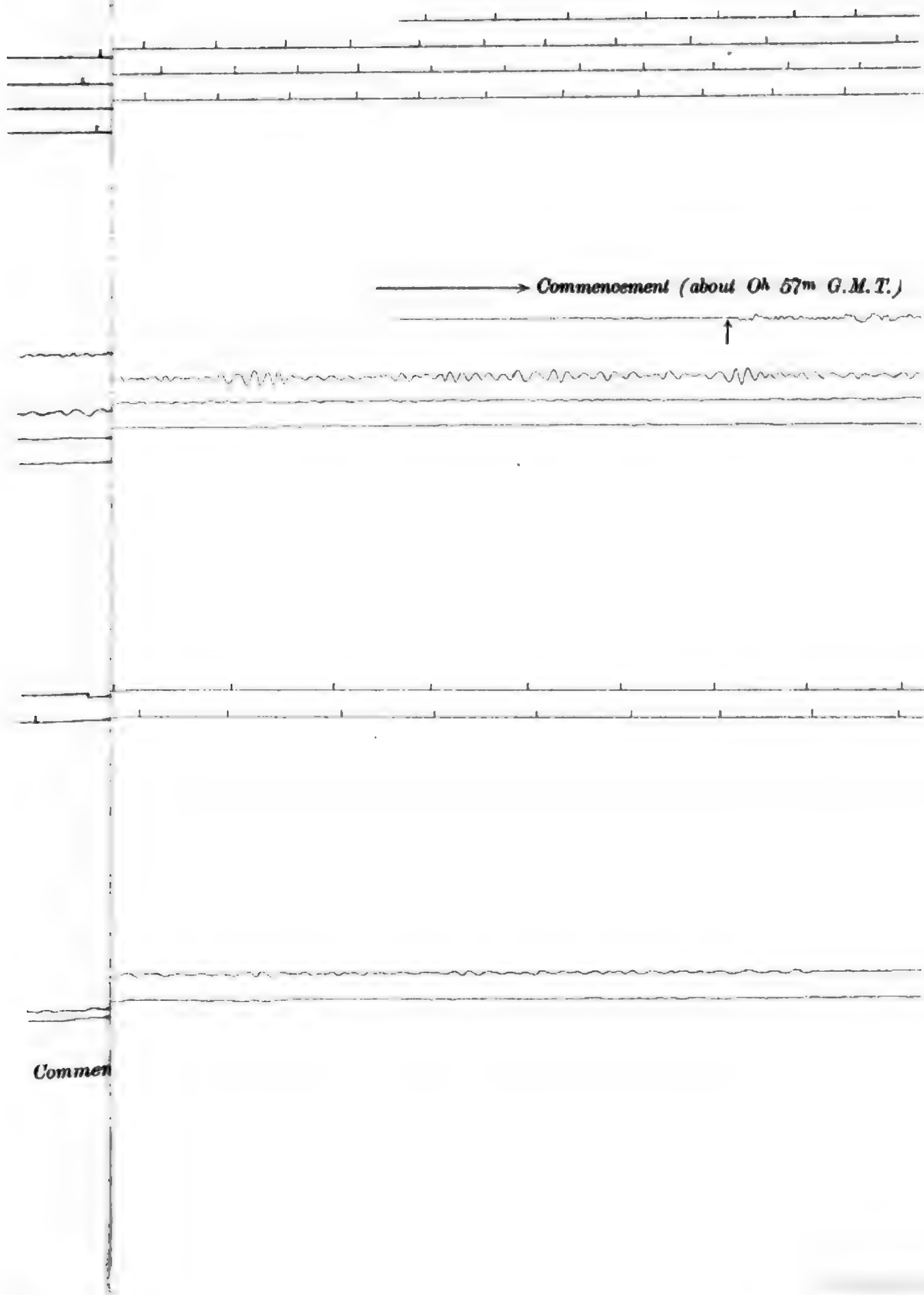
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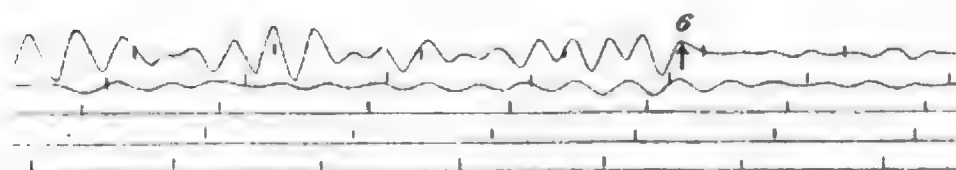
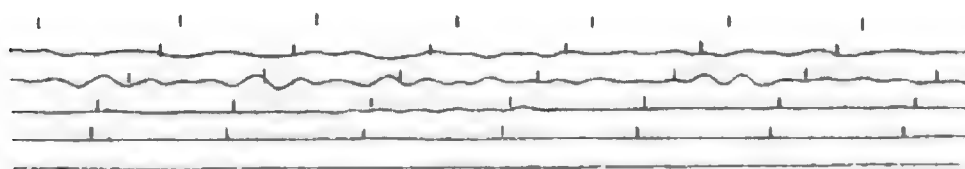


The successive epochs of the Earthquake Motion denoted by the numerals 1,2,3,4. 9 correspond to those denoted by the same numerals in the Tokyo NS Component Seismogram (Pl. II).



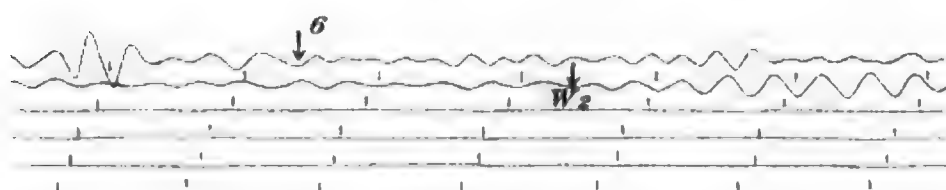
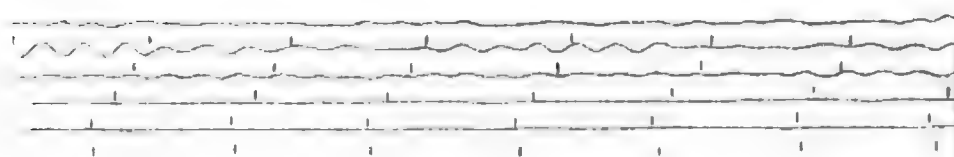


or Figs. 10, 11, and 12:- 1, 2, 3, 4, 5, 6, 7, correspond respectively to the commencements of the 1st and 2nd Preliminary Tremors, and the 1st, 2nd, 3rd, 4th, and 5th Phases of the Principal Portion.

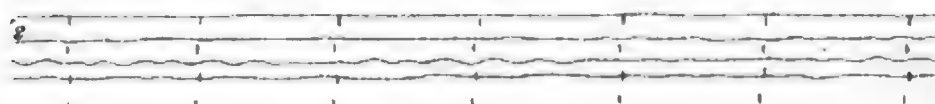


nd 11. Omori Type Horizontal Pendulum. Multipli

(I) is continued to (II), and (I') to (II').

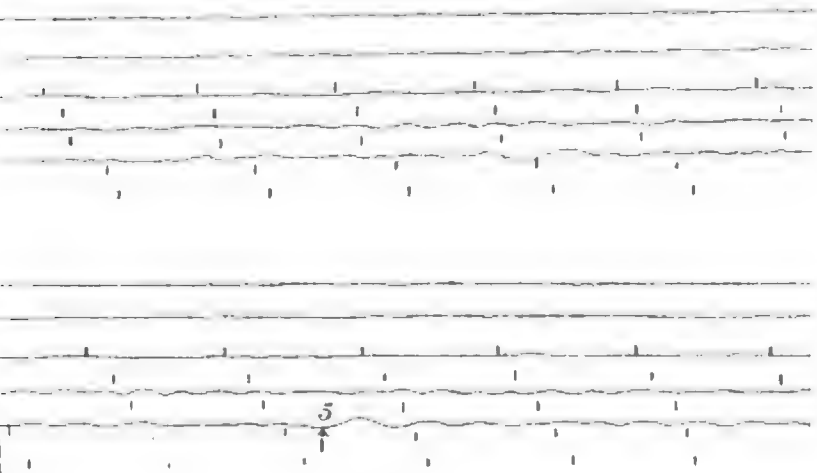


pendulum Period=about 19 sec. Multiplication=10

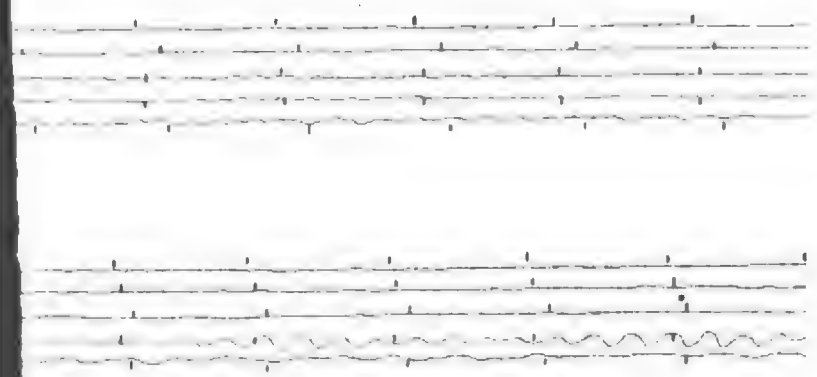


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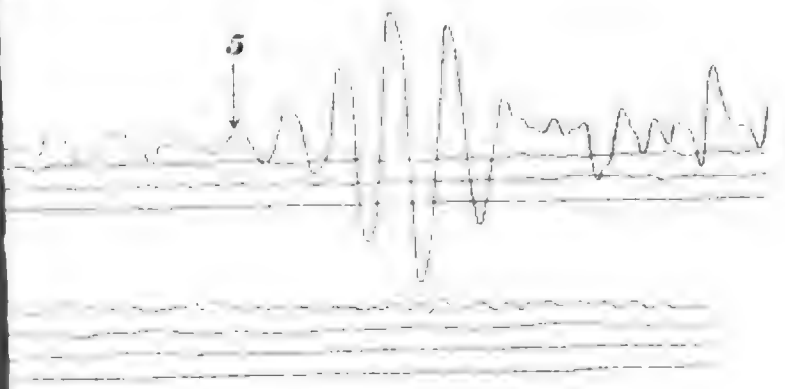
ltiplication=10. Time: 1 Interval:



NS COMPONENT.... { 1.... Commencement
W.... " "



Tremor. 5.... 1^h25^m22^s; Commencement of
6.... 1 34 52; " "
Principal Portion. 7.... 1 41 13; " "



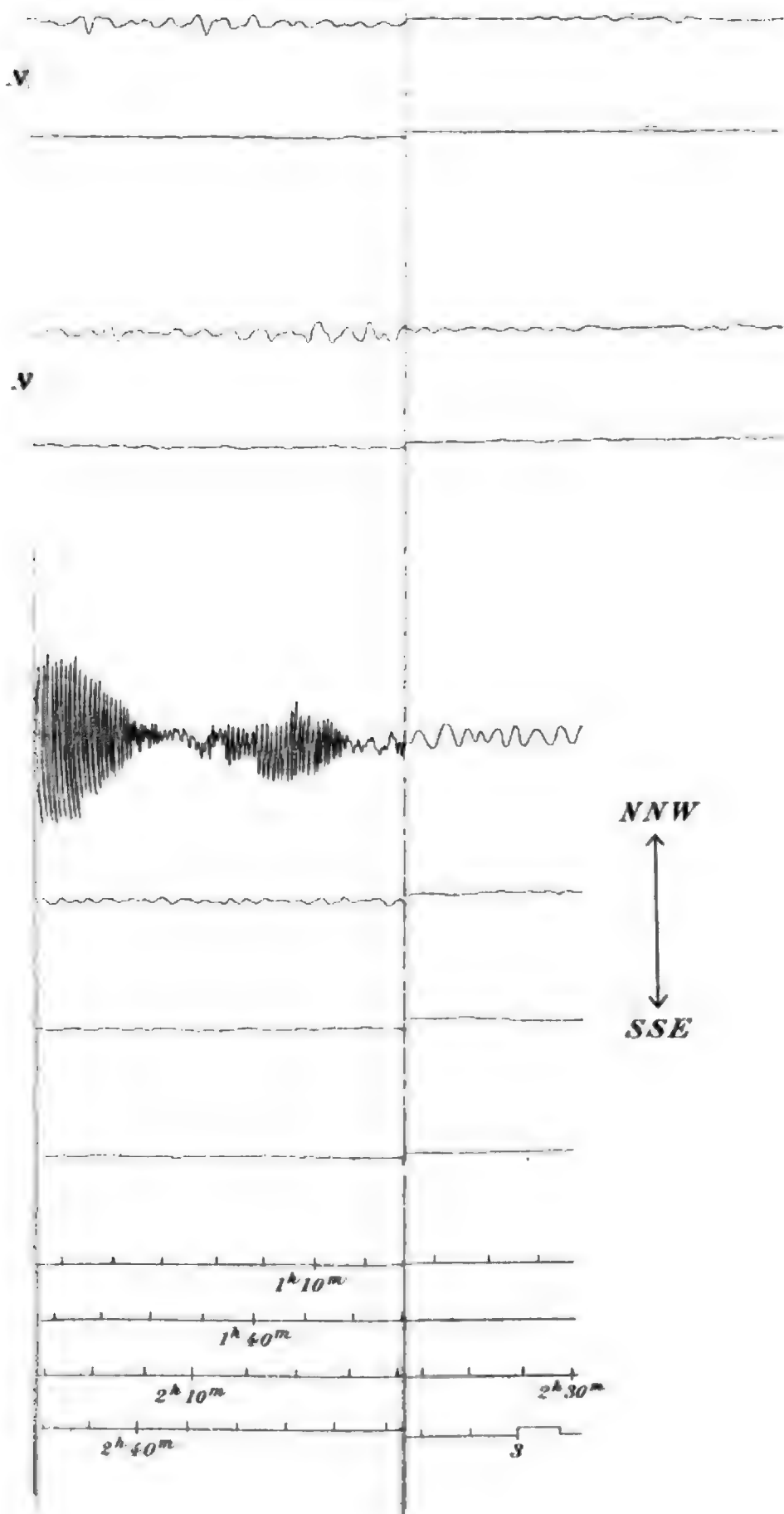
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Grande Sentinella.

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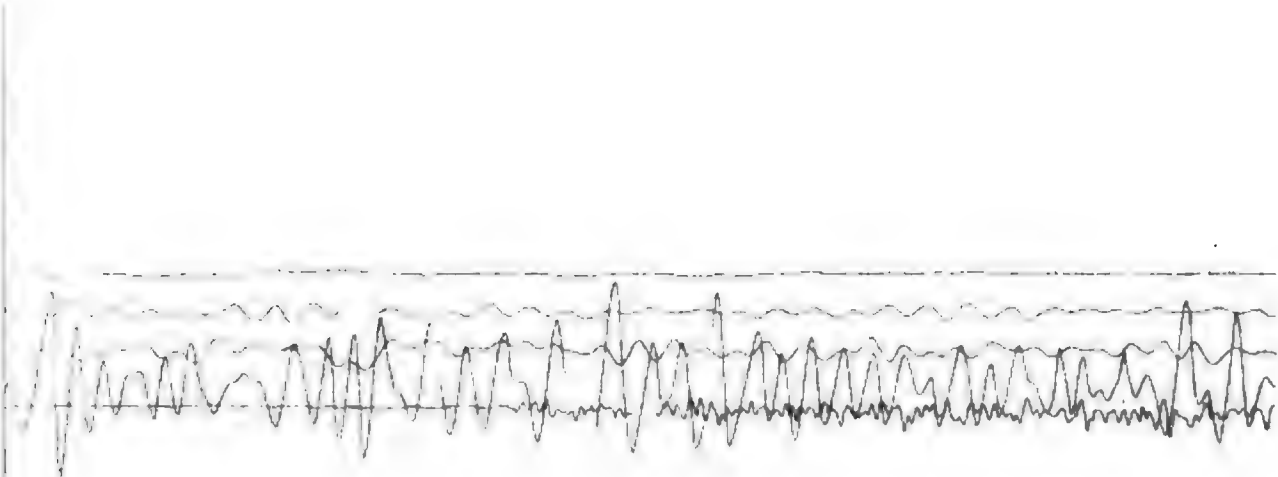


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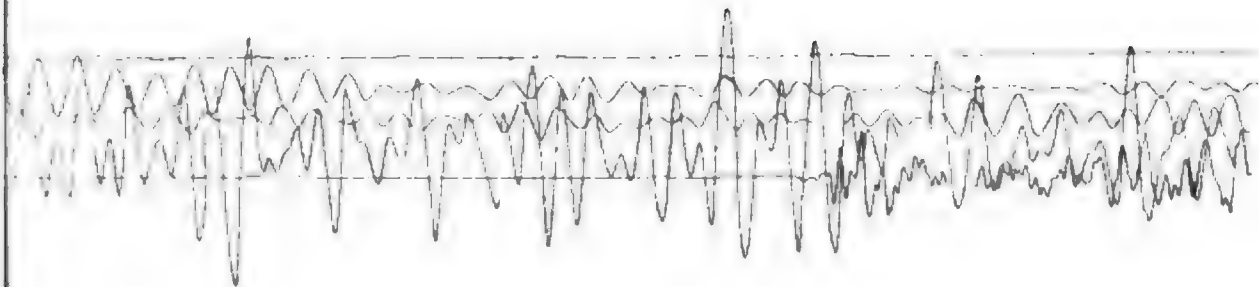


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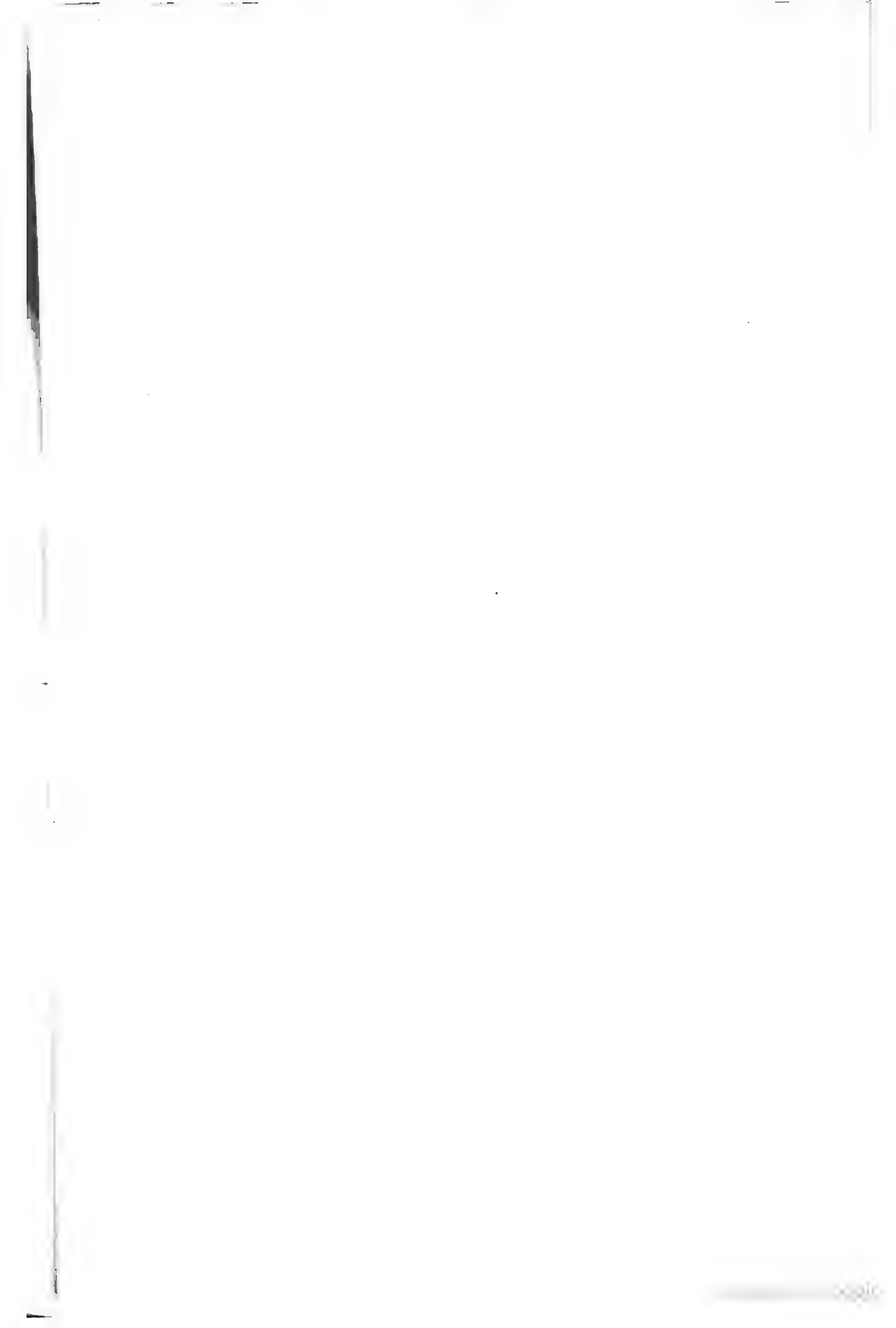
dem Seismogramm

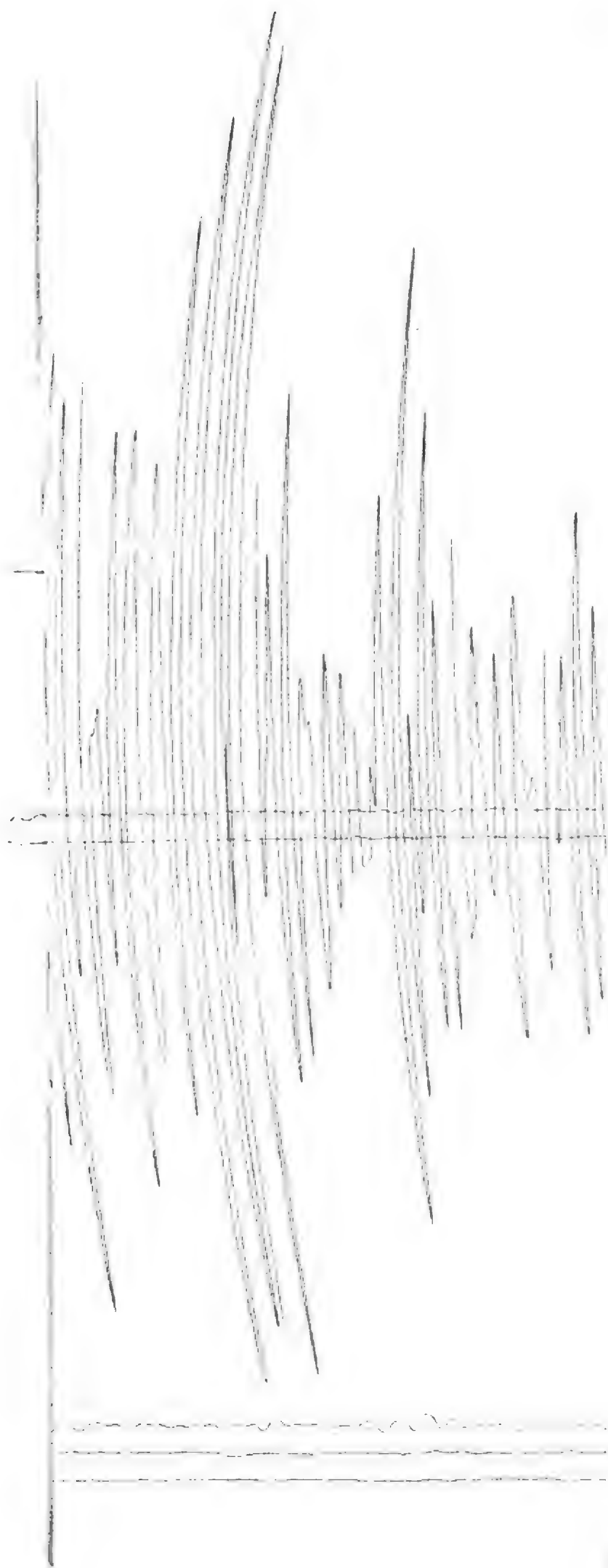
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REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

PART II: SEISMOGRAPHICAL OBSERVATIONS.

By

F. OMORI, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

Chapter I. Introductory.

1. *Himalayan Range and Seismic Activity.* The topography of British India is highly characteristic, the great Himalayan range forming a very beautiful circular arc which extends in an east-west direction. (See Fig. 1.) As elsewhere stated, great earthquake regions often coincide with the steep convex, or outer, side of a curve formed by a mountain chain or a series of islands; the inner, or concave, side being only disturbed by occasional local shocks.* In the case of the Himalayan range, which rises abruptly from flat plains of India, the arcuate form is probably due to a pressure from the Tibet side, which is still going on.

The large Indian seismic disturbance of April 4, 1905, usually known as the Kangra Earthquake, originated among the Sub-Himalayan chains in the Punjab (Fig. 1), and is to be regarded, together with the Assam and Bengal earthquake of June 12, 1897, as the result of the growth of the Himalayas. The latter form part of the great seismic zone extending from the Mediterranean on the west to Formosa on the east, along which no less than 11

* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 2.

large destructive earthquakes occurred within the 8 years between 1897 and 1905.*

2. *Area of Sensible Motion.* The approximate boundary of the area, within which the motion of the Kangra earthquake was sensible, is shown by the line B in Fig. 1, its western, southern, and eastern limits being Quetta (Afganistan), Surat and False Point, and Lakhimpur (Assam), respectively. The extreme distance, at which the motion was felt, was about 1670 km, the areas enclosed within the three isoseismals corresponding to Nos. 10, 9, and 8, of the Rossi-Forel scale of seismic intensity being, according to Mr. C. S. Middlemiss, of the Indian Geological Survey, respectively 200, 1600, and 2150 square miles.†

The meizoseismal district, where serious damage was caused, and whose intensity of motion corresponded to the Nos. VIII, IX, and X, of the Rossi-Forel scale, stretched in an NW-SE direction, from the vicinity of Kangra and Dharmsala to that of Mussooree and Dehra Dun, over a distance of about 350 km (A, Fig. 1); the earthquake motion being much stronger on the north-western half, than on the south-eastern half, of the zone under consideration. It seems probable that the latter extends towards the north-west of Kangra and Dharmsala for some more distance.

3. *Intensity of Motion.* The intensity, or destructive power, of the earthquake motion may be represented by the maximum acceleration of the earth's particle in its vibratory movement‡; the approximate values of this quantity at some places in the strongly or violently shaken areas, deduced from the observations

* The *Bulletin*, Vol. I, Nos. 1 and 2.

† C. S. Middlemiss: "Preliminary Account of the Kangra Earthquake of the 4th April 1905." Records of the Geological Survey of India, Vol. XXXII.

‡ See F. Omori: "Seismic Experiments on the Fracturing and Overturning of Columns." The *Publications*, No. 4.

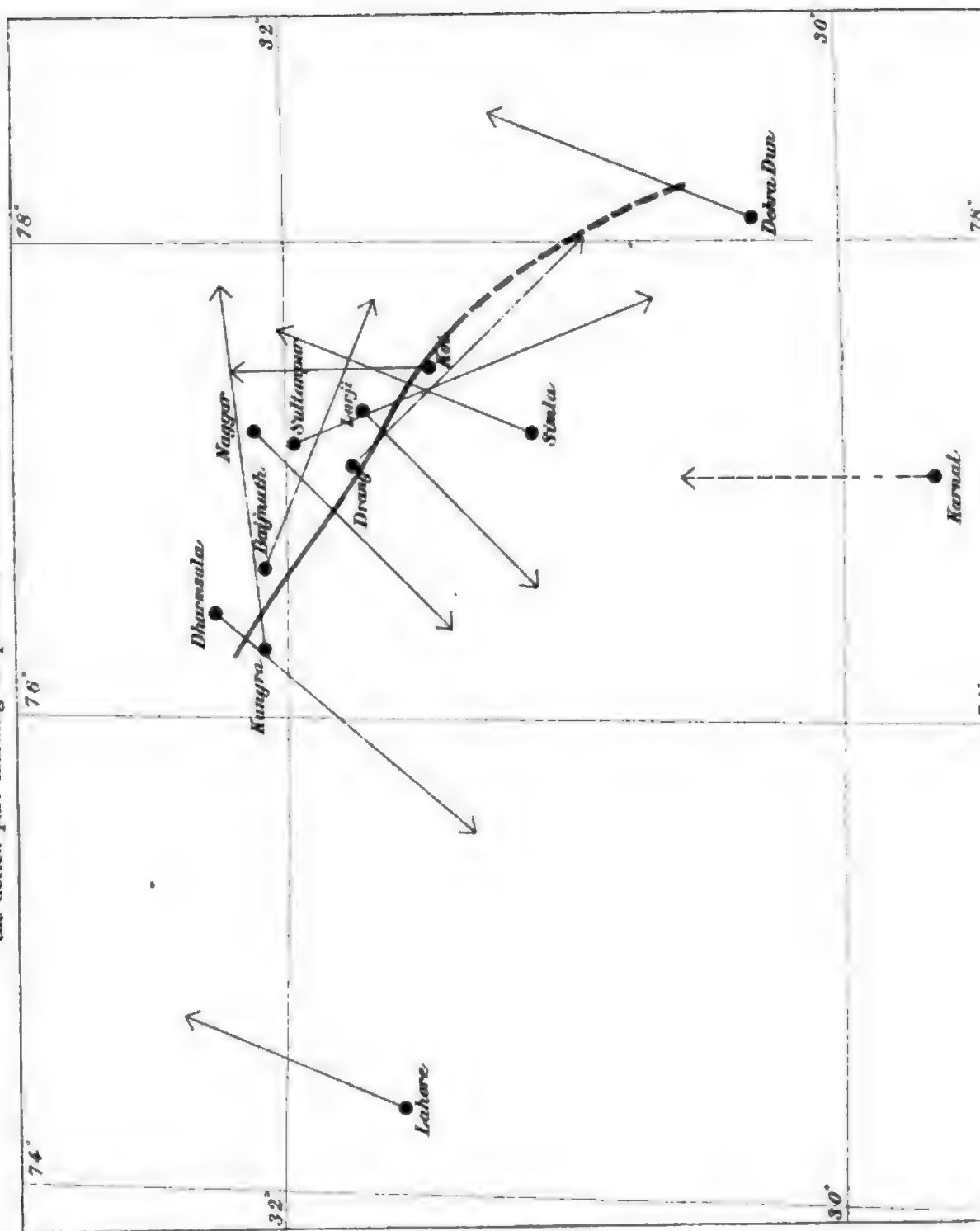
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2

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The Direction of Motion and the Epifocal Zone.

Arrow indicates the direction of motion. The thick red line indicates the Epifocal Zone, the dotted part marking its probable south-eastern continuation.



of overturned bodies, or inferred from the comparison of the earthquake effects in the present case with those in the great Mino-Owari (Central Japan) earthquake of 1891, being as follows :—

- Simla.* Max. acceleration=about 400 mm/sec².
Pathankot. Motion was weaker than at Simla.
Shahpore. Motion was much stronger than at Pathankot, and weaker than at Simla.
Rihlu. Motion was much stronger than at Shapore.
Lahore. Max. acceleration=about 500 mm/sec².
Amritsar. Motion was slightly weaker than at Lahore.
Delhi Motion was rather weaker than at Amritsar.
Upper Dharmasala. Max. acceleration was not greater than 2300 mm/sec².
Kangra. Max. acceleration was not greater than 3500 mm/sec².
Palampur. Max. acceleration was not greater than 2350 mm/sec².
Mandi. Max. acceleration was not greater than 2280 mm/sec².
Naggar. Motion was stronger than at Simla, but much weaker than at Sultanpur.

Thus it seems that the intensity of motion in the epicentral district of the Kangra earthquake was not so great as in that of the Mino-Owari earthquake of 1891. On the occasion of the latter catastrophe, the maximum acceleration of the earthquake movement in the Mino-Owari plain exceeded 4000 mm/sec², that in the epicentral zone of the famous Neco-Valley being much higher. Again, there was, in the Kangra earthquake, no surface manifestation of remarkable faults. These facts seem to indicate that the focus or centre of the earthquake under consideration was very deep below the surface.

4. Earthquake Damage. For the account of an absolute scale of strong seismic motion, or the destructive effects cor-

responding to different values of the maximum acceleration of the earthquake motion, the reader is referred to the *Publications*, No. 4. It is easy to understand that the amount of casualties and the number of houses destroyed by an earthquake depend largely on the method of buildings. Thus, badly built mud or stone houses are completely destroyed by an earthquake shock with an intensity of about 2000 mm/sec²., while properly built wooden or iron frame structures can resist any shock whatever. One special feature of the seismic effects on structures built with very bad material, which has practically no tensile strength, is that thickness of the walls gives no capacity of resisting seismic force. In fact a massive thick-walled house of inferior masonry work, which has no frame bindings, forms virtually a heap of stone and is simply shattered down at once by an earthquake shock; typical specimens of this sort being the barracks at Dhamsala, where many Garka soldiers were killed and wounded.

Ordinary buildings in the Kangra Valley, where the shock was strongest, had walls of mud or rubble masonry with a heavy slate roof, being of the worst type of structure with respect to the earthquake shock. The total number of the houses destroyed in the Kangra District and the Mandi State amounted to 112,477, and the number of persons killed reached 18,815, exceeding anything recorded of great seismic catastrophes in the recent times.*

5. Direction of Motion and the Earthquake Origin. The direction of the maximum earthquake motion at a given place may be assumed to be identical with the mean direction towards which different bodies are mostly overturned.† The directions

* Excepting the north Japan earthquake of June 15, 1896, which caused great tidal disturbances along the north-eastern coast of Japan, resulting in the death of 21,953 persons.

† See the *Publications*, Nos. 4 and 12.

thus estimated for a number of places in the strongly shaken area of the Kangra earthquake were as follows.

<i>Dharmsala.</i>	Towards S40° W.
<i>Kangra and Daulatpur.</i>	„ N83° E.
<i>Nagrotha.</i>	„ W a little S.
<i>Baijnath.</i>	„ E a little S.
<i>Drang.</i>	„ SE.
<i>Mandi.</i>	„ NE—SW (?)
<i>Sultanpur and Bajaura.</i>	„ S a little E.
Between <i>Sultanpur and Naggar.</i>	„ NE—SW (?)
<i>Kot.</i>	„ N.
<i>Larji.</i>	„ SW.
<i>Dehra Dun and Mussooree.</i>	„ NEN.
<i>Lahore.</i>	„ N a little E.
<i>Simla.</i>	Towards N a little E—S a little W.
<i>Karnal.*</i>	„ N.

The direction of motion as above given are to be regarded as only gross approximations, the observations being in many instances unsatisfactory or few in number. One marked fact, however, is that the direction at Kangra was towards E a little N, and therefore nearly opposite to that at Dharmsala where the direction was towards SW. Further, comparing together the results for the different places, we see that the latter may be grouped into 2 sets as follows:—

Group A:—Lahore, Kangra, Simla, Kot, Dehra Dun, Karnal.

Group B:—Dharmsala, Naggar, Baijnath, Sultanpur, Drang, Larji.

At A Group places, the direction of motion was towards N, NEN, or ENE, while at B Group places it was towards SW, SES,

* The direction at Karnal has been inferred from the observation of Mr. Hanly, Assistant Engineer, Dharmsala.

or ESE, so that the maximum earthquake movements at these two different sets of places may be regarded, on the whole, to be opposite to one another, as shown in Fig. 2, probably denoting a certain symmetry of the direction of motion with respect to the earthquake origin. The red line in the figure, drawn midway between *A* and *B* Group places, is to be regarded as marking the epifocal zone, and the dotted line indicates the possible extension towards the southeast; the entire length of the focus thus supposed being about 270 km or 170 miles. The most central point of the seismic disturbance may be assumed to be situated some distance to the SE of Dharmsala and Kangra, say, at

Latitude, 31° 49' N.

Longitude, 77° 00' E.

This position has been taken as the earthquake centre in the calculations of the propagation velocities of the different phases of the earthquake motion.

6. List of Stations. Table I gives for each of the 69 different stations, where the Kangra Earthquake was observed, the latitude, longitude, epicentral distance ($=x$), and the time ($=t_1$) of earthquake occurrence.* The last named element of motion was deduced from the seismograms, except in the 5 cases marked (*M*), whose epicentral distance was under $21\frac{3}{4}$, and whose time of commencement, obtained from magnetograph records, may be regarded as corresponding to the beginning of the "principal portion."

The times are always given in G.M.T.

The earthquake was insensible at all the places given in the table, except Dehra Dun, where the motion was severe; the nearest and furthest teleseismic stations being respectively Taschkent ($x=11\ 20'$) and Tacubaya ($x=128\ 39'$).

* The time of earthquake occurrence at the origin itself is given in the next Chapter.

The epicentral distance x has been calculated by the following formula :—

$$\cos x = \sin \phi. \sin \phi_0 + \cos \phi. \cos \phi_0. \cos(\lambda - \lambda_0),$$

where ϕ and λ denote the latitude and longitude of a given station, and ϕ_0 and λ_0 those of the epicentre.

TABLE I. List of Stations ; Observation of the Indian Earthquake of April 4, 1905.

Station.	Position.		Epicentral Distance = x	Time of Eqke Occurrence. = t_1 (G.M.T.)
	Latitude.	Longitude.		
Epicentre.	31° 49' — N	77° — — E	————	0^h49^m48^s (= t_0)
India.				
Dehra Dun.	30°19'19'' N	78°03'19'' E	1° 45'	(M) 0 ^h 50 ^m 38 ^s
Colaba (Bombay)	18°53'45'' N	72°48'56'' E	13 28...	(M) 0 53 08
Barrackpur	22°46'29'' N	88°21'39'' E	13° 32'	(M) 0 55 41
Alipore (Calcutta)	22°34' — N	88°24' — E	13 42	0 52 00
Kodaikanal	10°13'50'' N	77°27'46'' E	21 35 ...	(M) 1 01 00
Burma.				
Taungoo.	18°55'45'' N	96°27'03'' E	21° 44'	(M) 1 ^h 00 ^m 03 ^s
Russian Turkestan				
Taschkent	41°19'31'' N	69°17'42'' E	11° 20'	0 ^h 52 ^m 24 ^s
Caucasus. (Russia)				
Tiflis	41°43'08'' N	44°47'51'' E	27° 26'	0 ^h 55 ^m 48 ^s
Achalkalaki	41 25 — N	43 29 09 E	28 21	0 55 59
Batum	41 40 — N	41 38 35 E	29 45	0 56 14
Borshom	41 51 — N	43 23 08 E	28 30	0 55 52
Derbent	42 04 — N	48 18 — E	24 58	0 55 03
Schemachn	40 38 — N	48 38 — E	24 23	0 55 09
Siberia.				
Irkutsk	52°16' — N	104°18'33'' E	28° 28'	0 ^h 55 ^m 44 ^s

TABLE I. *Cont.*

Station.	Position.		Epicentral Distance = r .	Time of Eque Occurrence = t_1 (G.M.T.)
	Latitude.	Longitude.		
Asia Minor. Bairut	33°54' — N	35°30' — E	34° 41'	0 ^h 58 ^m 00 ^s
Russia. Jurjew	58°22'48" N	26°43'20" E	42° 49'	0 57 52
Nikolajew	46 58 18 N	31 58 27 E	37 20	0 58 54
Java. Batavia	6°08' — S	106°50' — E	42° 35'	0 58 33
Philippines. Manila	14°34'41" N	120°58'33" E	43° 34'	0 58 25
China. Shanghai (Zikawei)	31°11'33" N	121°10'45" E	37° 24'	0 53 17
Japan. Tōkyō	35°42'33" N	139°45'53" E	51° 26'	0 ^h 59 ^m 08 ^s
Mizusawa	39 08 — N	141 07 — E	51 39	0 59 08
Kōbe	34 41 — N	135 11 — E	48 03	0 58 26
Ōsaka	34 42 — N	135 31 — E	48 19	0 58 51
Tadotsu.	34 17 — N	133 46 — E	47 02	0 58 49
Formosa (Japan). Taihoku	25°02' — N	121°30' — E	39° 27'	0 57 19
Taichu	24 09 — N	120 42 — E	39 05	—
Tainan	22 59 — N	120 12 — E	39 06	—
Mauritius.	20°11' — S	57°31' — E	55° 15'	0 58 54
Servia. Belgrade.	44°48' — N	20°09' — E	45° 29'	0 57 47
Germany. Potsdam.	52°22'56" N	13°03'59" E	49° 48'	0 ^h 58 ^m 46 ^s
Leipzig.	51 20 06 N	12 23 30 E	50 16	0 58 44
Jena.	50 56 — N	11 35 — E	50 48	0 58 54
Hamburg.	53 33 55 N	10 01 19 E	51 34	0 58 14
Göttingen.	51 33 — N	9 58 — E	51 45	0 58 55
Strassburg.	48 35 00 N	7 46 10 E	53 31	0 58 26

TABLE I. *Cont.*

Station.	Position.		Epicentral Distance = x .	Time of Eque Occurrence = t_1 (G.M.T.)
	Latitude.	Longitude.		
Austria-Hungary.				
Krakau	50°03'50'' N	19°57'36'' E	45° 30'	0 58 12 ^s
Laibach	46 03 — N	14 30 — E	49 19	0 58 46
Triest.	45 38 45 N	13 45 45 E	49 52	0 58 44
Pola.	44 51 49 N	13 50 44 E	49 55	0 58 50
Sweden.				
Upsala.	59°51'30'' N	17°37'30'' E	47° 41'	0 58 22
Italy.				
Messina.	38°11'45'' N	15°33'18'' E	49° 46'	0 59 00
Port d'Ischia.	40 44 27 N	13 56 34 E	50 30	0 58 56
Rocca di papa.	41 46 — N	12 42 — E	51 15	0 58 51
Querce (Florence).	43 47 18 N	11 16 42 E	51 54	0 59 08
Ximeniano. (,,)	43 46 40 N	11 15 24 E	51 55	0 58 33
Quarto-Castello (,,)	43 49 11 N	11 13 11 E	51 56	0 58 47
Padova.	45 24 3 N	11 52 18 E	51 20	0 58 58
Great Britain.				
Kew	51°28'06'' N	0°18'46'' W	58° 05'	1 00 12
Edinburgh.	55 57 23 N	3 10 46 W	58 48	1 00 00
Birmingham.	52 28 — N	1 53 — W	58 49	1 00 35
Shide (I. W.)	50 42 — N	11 9 — W	58 52	1 01 00
Liverpool (Bidston).	53 24 04 N	3 04 18 W	59 18	1 00 36
Paisley.	55 51 — N	4 25 — W	59 30	1 00 00
Spain.				
San Fernando.	36°27'40'' N	6°12'19'' W	66° 47'	1 02 30
Azores.				
Ponta Delgada.	37 46 — N	25 41 — W	79 54	1 01 00
Cape of Good Hope.				
	33 56 03 S	18 28 41 E	85 46	1 02 30
Canada.				
Victoria, B.C.	48 27 — N	123 22 — W	97 42	1 06 48
Toronto.	43 39 36 N	79 23 24 W	101 30	1 06 36
Hawaii.				
Honolulu.	21 19 — N	153 04 — W	108 27	1 04 36

TABLE. I. *Cont.*

Station.	Position.		Epicentral Distance = x .	Time of Earth- quake Occurrence = t_1 (G.M.T.)
	Latitude.	Longitude.		
United States.				
Baltimore.	39°17'48" N	76°37'12" W	104° 47'	1 ^h 10 ^m 30 ^s
Washington.	38 54 18 N	77 03 06 W	105 17	1 08 25
Cheltenham	38 44 00 N	76 50 30 W	105 22	1 08 39
Porto Rico.				
Vieques.	18 09 — N	65 26 — W	118 25	1 10 25
Samoa (Apia)				
	13 48 24 S	171 45 54 W	115 08	1 01 36
New Zealand.				
Christchurch.	43 31 50 S	172 37 18 E	115 03	1 10 00
Wellington.	41 17 — S	174 47 — E	115 45	1 09 48
Brazil.				
Rio de Janeiro.	22 54 24 S	43 10 21 W	126 53	1 59 41(?)
Mexico.				
Tacubaya.	19 24 18 N	99 11 37 W	128 39	1 11 25

7. *Directions of Observing Stations relative to the Earth-quake Origin.*

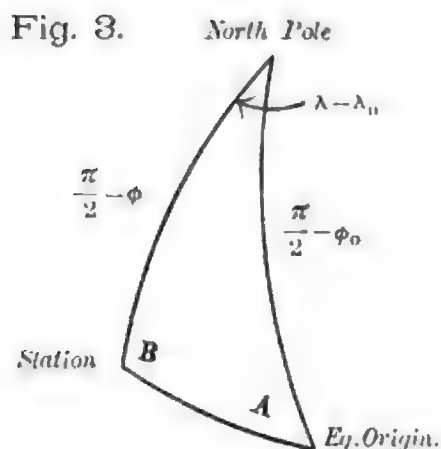


Table II gives, for a number of the observing places, besides the epicentral arcual distance (x) expressed in km, the azimuth (A) of a given station with respect to the earthquake origin, and the azimuth (B) of the latter with respect to the former, both counted from the north.* (See Fig. 3, in which ϕ and ϕ_0 have

* This calculation has very kindly been undertaken by Mr. K. Ōi, Assistant Professor in the Science and Engineering College, Kyōto Imperial University.

the same meanings as in the preceding §). The azimuths A and B have been calculated by the following formulae:—

$$\sin A = \frac{\cos \phi_0 \cdot \sin(\lambda - \lambda_0)}{\sin x};$$

$$\sin B = \frac{\cos \phi_0 \cdot \sin(\lambda - \lambda_0)}{\sin x}.$$

TABLE II. Distance and Azimuth of Observing Stations.

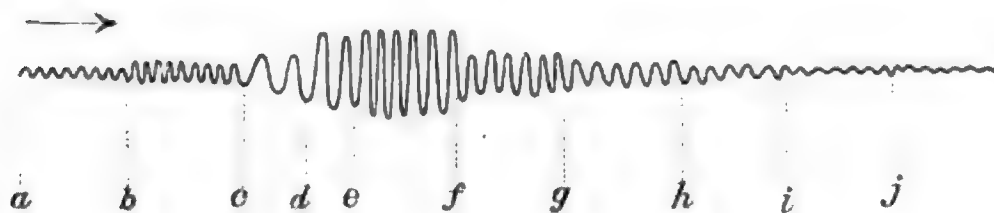
Station.	Epicentral Distance.		Azimuth A . (from North)	Azimuth B . (from North)
	in Angle.	in km.		
Tiflis.	27°26'06"	3050	W 59°41'37"	E 79°22'20"
Osaka.	48 19 11	5372	E 69 50 31	W 75 59 26
Potsdam.	49 47 46	5536	W 42 52 56	E 88 02 40
Tokyo.	51 25 47	5718	E 67 25 58	W 75 05 36
Göttingen.	51 45 10	5754	W 46 48 18	E 85 01 10
Quarto-Castello.	51 56 07	5774	W 56 41 45	E 79 49 50
Kew.	58 05 04	6458	W 45 43 22	E 77 35 10
San Fernando.	66 47 11	7425	W 60 20 17	E 66 39 00
Toronto.	101 29 49	11285	W 17 11 54	E 20 19 16
Washington.	105 16 39	11705	W 20 40 11	E 22 40 14
Cheltenham.	105 22 21	11716	W 20 53 42	E 22 51 43
Christchurch.	115 03 11	12792	E 127 12 26	W 68 59 01
Wellington.	115 44 30	12868	E 124 15 11	W 69 10 26
Rio de Janeiro.	126 53 19	14108	W 96 10 58	E 66 32 04
Tacubaya.	128 38 55	14303	W 4 35 54	E 4 08 31

As will be seen from the above table, Tacubaya lies very nearly on the meridian passing through the earthquake centre; while the azimuth (B) for Tiflis, Osaka, Tokyo, Potsdam, Göttingen, Quarto-Castello, and Kew, is not much different from 90°, varying between 75° and 88°. It may be concluded, therefore, that the NS and EW components of the seismogram at Tacubaya corresponded almost exactly to the *longitudinal* and *transverse waves* respectively. On the contrary, the same two components at the

7 other above named stations approximately corresponded to the *transverse* and *longitudinal waves*, respectively. Of the remaining places given in the table, Toronto, Washington, and Cheltenham, are situated not very much out of the meridian through the origin of disturbance, while the azimuth for San Fernando, Christchurch, Wellington, and Rio de Janeiro, was nearly 70° . The approximate relation to the position of the earthquake centre of the other stations not above mentioned may be inferred from that for those places given in the table.

8. Character of the Teleseismic Motion. The earthquake motion due to a distant origin consists generally of a series of different sections or stages, in each of which the period* remains essentially constant, while the amplitude is also on the whole constant, except for the occurrence of maximum and minimum groups.

Fig. 4.



The successive sections of the earthquake motion, illustrated in Fig. 4, are as follows.

The *preliminary tremor* (*a b c*), which consists principally of vibrations of small amplitude and of comparatively short period, is divided into the 1st *section* or the *first preliminary tremor* (*a b*), and the 2nd *section* or the *second preliminary tremor* (*b c*). Commencement of the latter is marked by an increase of the amplitude and, in many cases, also by the appearance of slow vibrations.

* The term "Period" is used in the sense of the *complete period*.

The *principal portion*, which comprises the 3rd to 7th *sections* (*cd, de, ef, fg, gh*), denotes the most active part of an earthquake, which follows the preliminary tremors and consists of movements of larger amplitude. The subdivisions of the *principal portion* are as follows:—The *1st phase* (3rd *section*), consisting of a few very slow vibrations; the *2nd phase* (4th *section*), consisting also of slow movements whose period is somewhat shorter than in the 1st phase; the *3rd phase* (5th *section*), consisting of vibrations of period much quicker than that in the preceding two phases; the *4th phase* (6th *section*) and the *5th phase* (7th *section*), the vibrations in these two stages being quicker and smaller than in the 3rd phase.

Lastly, the *end portion*, or *tail*, which comprises the 8th and subsequent *sections*, (*hi,*) denotes the feeble finishing part of the earthquake motion, following the principal portion.

In earthquakes of near origin, the motion is, on account of the predominance of quick vibrations of macro-seismic character, much more complex than in distant earthquakes, it being generally difficult to subdivide the principal portion into the different phases.

Range of Motion (Double Amplitude) and Duration. The relative magnitudes of vibrations in the successive sections, or stages, of the teleseismic disturbance are different from those of the near earthquake motion, the predominating periods in each epoch being different according to the epicentral distance. In the case of the 11 large distant earthquakes observed between 1899 and 1902 in Tokyo, the relative magnitudes of motion in the successive sections of motion were as shown in the 2nd column of Table III. From the latter it will be seen that the range of motion in the 1st preliminary tremor (1st section) was only about $\frac{1}{5}$ th or $\frac{1}{6}$ th of that in the 2nd and 3rd sections, namely, the 2nd



with the two periods Q_1 and Q_2 of the "pulsatory oscillations." Other periods of microseismic or insensible nature, which are of a more or less frequent occurrence may be denoted by $P_3, P_4, P_5, \dots, P_{13}, \dots$. The average values of the different periods are as follows :—

$P_1 = 4.2$ sec.	$P_8 = 32.3$ sec.
$P_2 = 8.7$..	$P_9 = 35.4$..
$P_3 = 14.1$..	$P_{10} = 41.8$..
$P_4 = 17.5$..	$P_{11} = 45.0$..
$P_5 = 20.4$ ..	.....
$P_6 = 24.9$..	$P_{13} = 54.0$..
$P_7 = 28.3$ ..	.....

In the 4th column of Table III, which gives the periods of the predominating vibrations in the different sections of motion of the same 11 great teleseismic disturbances, those of a specially frequent occurrence are printed in fat characters.

TABLE III. Amplitude, Duration, and Periods of Great Teleseismic Motion. (Tokyo Observation, 1899–1902.)

Phase of Motion.	Relative Amplitude.	Relative Duration.	Predominating Periods.
1st Preliminary Tremor.	100	100	$P_1; \textbf{P}_2; P_3$
2nd " " "	560	95	$P_1; \textbf{P}_2; P_3; \text{---}; \text{---}; P_6; P_7$
1st Phase, Princ. Portion.	550	30 | 79	$\text{---}; P_2; \dots P_9; P_{10}; \dots P_{13}$
2nd " " " "	1820	49 |	$\text{---}; P_2; \dots P_7; \textbf{P}_9; P_{10}$
3rd " " " "	1220	91	$\dots \textbf{P}_5; P_6$
4th " " " "	840	95	$\text{---}; P_2; \textbf{P}_3; P_5$
5th " " " "	560	95	$\text{---}; P_2; \textbf{P}_3$
8th Section (Tail)	430	88	$\text{---}; \text{---}; \textbf{P}_3$
End Portion (Tail).	—	—	$\text{---}; \textbf{P}_2; P_3; P_5$

As will be seen from the above table, the period P_2 ($=8.7$

sec.), which occurred very frequently in the 1st and 2nd preliminary tremors, happened more or less almost through the entire series of the different sections of motion. In the 2nd preliminary tremor, slow periods of P_6 ($=24.9$ sec.) and P_7 ($=28.3$ sec.) began to appear; while in the 1st phase of the principal portion, very slow periods of P_{10} ($=41.8$ sec.) and P_{13} ($=54.0$ sec.), were of a frequent occurrence. In the 2nd phase of the same portion, the predominating period became a little shorter and P_9 ($=35.4$ sec.) occurred very often. In the 3rd phase of the principal portion, the vibrations still further quickened, the period of P_8 ($=20.4$ sec.) occurring most frequently. In the two subsequent phases of the principal portion and the 1st phase of the tail, the predominating period was P_3 ($=14.1$ sec.). Towards the end of motion the period of common occurrence became again P_2 ($=8.7$ sec.), being the same as that prominent in the 1st and 2nd preliminary tremor.

The foregoing short account of the teleseismic motion, based on the previous observations made in Tokyo, has been given for the sake of reference, the complete discussion on the character of the vibrations being reserved for a later chapter.

9. *Time of Occurrence of the Kangra Earthquake.*

(i) *Time of Earthquake Occurrence inferred from Teleseismic Records.*

The time ($=t_0$) of earthquake occurrence at the origin itself may be estimated by the following formula* :—

$$t_0 = t_1 - 1.165 y_1 \dots \dots \dots (1)$$

in which t_1 and y_1 denote respectively the time of commencement, and the duration of the 1st preliminary tremor, of the earthquake motion at a given observing station. This equation is to be regarded as being roughly approximate, but seems to give fairly

* The Bulletin of the Imperial Earthquake Investigation Committee, Vol. 1, No. 1.

satisfactory results; the time of occurrence at the origin, estimated by (1), agreeing in the cases of the Calabrian earthquake of Sept. 8, 1905, and of the San Francisco earthquake of April 18, 1906, almost to within 1 minute.

For the time of commencement (t_0) of the Kangra earthquake, we have, applying, for example, the Tokyo observation to the equation (1):—

$$t_1 = 0^h 59^m 08^s \text{ (G.M.T.)}; y_1 = 7^m 16^s.$$

$$t_0 = 0^h 59^m 08^s - (1.165 \times 436s) = 0^h 50^m 40^s \text{ (G.M.T.)}$$

Again, taking the averages from the observations at the 18 stations of Tokyo, Osaka, Mizusawa, Tadotsu, Kobe, Upsala, Laibach, Triest, Pola, Potsdam, Leipzig, Göttingen, Messina, Ischia, Rocca di papa, Querce, Ximeniano, and Quarto-Castello, whose epicentral distance varied between $47^\circ 02'$ and $51^\circ 56'$, we obtain:—

$$\text{mean } t_1 = 0^h 58^m 58^s \text{ (G.M.T.)}; y_1 = 7^m 12^s$$

$$t_0 = 0^h 58^m 58^s - (1.165 \times 432^s) = 0^h 50^m 35^s \text{ (G.M.T.)}$$

These values of t_0 agree very well with the time of occurrence at the origin inferred from the magnetograph observations made at Dehra Dun, namely, $0^h 49^m 48^s$, G.M.T. (See the next §.)

(ii) *Earthquake Recorded by Magnetographs.*

The only instrumental record of the shock within the meizo-seismal area is that given by the magnetograph at Dehra Dun, which is thus extremely valuable in connection with the determination of the time of earthquake occurrence at the origin of disturbance. The following detailed account respecting the magnetograms obtained at Dehra Dun and three other stations of Barrackpore (near Calcutta), Kodaikanal (Madras), and Taungoo (Burma), has very kindly been furnished by Captain Thomas, the officer in charge of the Magnetic Department at Dehra Dun, and his assistant,

Mr. Mazumdar ; a very useful check on the time found for each place consisting in comparing the interval between the earthquake shock and a well marked apex in magnetic disturbances either preceding or following the latter.

**“On the Time of the Principal Earthquake Shock
on the 4th April 1905 as registered on
Magnetograph Curves.**

“ *Accuracy of Measurement.* The process of measuring the exact moment of time of a particular point on the trace is burdened with several sources of error, in the measurement of small quantities.

“ The accordance, however, of many of the results in the following §§ when independent measures were taken by two or more observers, is such that there should be no hesitation in accepting some groups as correct at least to 1 minute of time.

“ There is moreover a check on the times found for each observatory, by comparing the intervals derived from the time of shock at each observatory with the intervals obtained by measuring the interval between the shocks and the well marked apices of disturbances on the same date.

“ Two apices of disturbance have been utilized and the measurement has been made in two ways. An additional advantage applies to these methods in that error of cut off, parallax, and error of clock are not involved.

“ In the first the absolute time of the apex of disturbance is found and the time interval derived by applying the absolute time of the shock already determined.

“ In the second the interval is measured direct

“ *Method of obtaining Time at the various observatories.* Before tabulating the results of the measurements of the magnetograms, and comparing them as above suggested, it would be well to briefly indicate the methods of obtaining correct time at the various observatories.

“ At Dehra Dun time is obtained by comparison of the observer's

chronometer with the sidereal clock at least twice a week, errors on other days being interpolated by the rates thus obtained.

“At Barrackpore and Taungoo time is obtained by observations to E and W stars.

“At Kodaikanal time is obtained by telegraphic signal from Madras daily and the observer's chronometer is compared daily with the Solar Physics Observatory clock.

“At all observatories the driving clock of the magnetographs is compared daily with the standard chronometer by means of a pocket chronometer but as before stated in the absence of a second hand on the driving clock, this determination is likely to be in error some seconds.

Time of principal shock measured from magnetographs.

“I. Direct measurement of time of shock. (All in Madras time, corrected for errors of clock, parallax and cut off).

Observer*	Capt. Thomas	Mazumdar	Omori
Dehra Dun ...	(H) 6 ^h —11 ^m —43 ^s (δ) 6—11—48	6 ^h —11 ^m —29 ^s 6—11—46	6 ^h —11 ^m —27 ^s 6—11—33
	(Mean=6—11—38.)		
Barrackpore ..	(H) 6—16—12 (δ) 6—17—5	6—16—26 6—16—50	6—16—29 6—16—55
	(Mean=6—16—41)		
Kodaikanal...	(H) 6—21—40 (δ) 6—22—4	6—21—37 6—22—36	6—21—30 6—22—30
	(Mean=6—22—0)		
Taungoo	(H) 6—20—3 (δ) very faint—not measured	6—19—45	6—19—58
	(Mean=6—19—55)		

These give intervals:—

Dehra Dun—Barrackpore	= 5 ^m —03 ^s
„ —Kodaikanal	= 10—22
„ —Taungoo	= 8—17

* H from HF curve; δ from Decl. curve.

“ II. Measurement of time interval between an apex (*a*) of magnetic disturbance and time of the earthquake shock.*

(i) Absolute time of apex of disturbance (*a*).

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
9 ^h —12 ^m —22 ^s	9 ^h —12 ^m —09 ^s	9 ^h —12 ^m —21 ^s	9 ^h —11 ^m —11 ^s

Subtracting these values from the time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—0—41	2—55—35	2—50—21	2—51—17

This gives times for interval:—

$$\begin{aligned} \text{Dehra Dun—Barrackpore} &= 5^m—06^s \\ \text{„ —Kodaikanal} &= 10—20 \\ \text{„ —Taungoo} &= 9—24 \end{aligned}$$

(ii) Direct measurement of time interval.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—0—30	2—55—22	2—50—17	2—51—3

This gives times for interval:—

$$\begin{aligned} \text{Dehra Dun—Barrackpore} &= 5^m—09^s \\ \text{„ —Kodaikanal} &= 10—08 \\ \text{„ —Taungoo} &= 9—28 \end{aligned}$$

“ III. Absolute time of an apex of magnetic disturbance (*b*).

(i) Dehra Dun	Barrackpore	Kodaikanal	Taungoo
2—31—46	2—31—40	2—31—45	2—30—35

Subtracting time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—40—00	3—44—59	3—50—15	3—49—38

The differences are:—

$$\begin{aligned} \text{Dehra Dun—Barrackpore} &= 4^m—59^s \\ \text{„ —Kodaikanal} &= 10—15 \\ \text{„ —Taungoo} &= 9—38 \end{aligned}$$

(ii) Direct measurement of interval from apex (*b*) to principal shock.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—39—51	3—44—54	3—49—55	3—49—16

* The measurements here given are the means of those made by Capt. Thomas and Mr. Muzumdar separately.

These give the time differences :—

$$\begin{aligned} \text{Dehra Dun—Barrackpore} &= 5^m-03^s \\ \text{,, —Kodaikanal} &= 10-04 \\ \text{,, —Taungoo} &= 9-25. \end{aligned}$$

“IV. Absolute times of disturbances. As found these are

	Disturbance (b)	Disturbance (a)	Difference (a)-(b)
Dehra Dun	2—31—46	9—12—22	6—40—36
Barrackpore	2—31—40	9—12—09	6—40—29
Kodaikanal	2—31—45	9—12—20	6—40—35
Taungoo	2—30—35	9—11—11	6—40—36

$$\text{Difference, Mean—Taungoo} = 1^m 08^s$$

This proves that the disturbances are simultaneous at all observatories within the limits of measurement and that Taungoo time is slow $1^m 08^s$ while the time at the other three observatories is very good. This conclusion is further borne out by consideration of the interval Dehra Dun-Taungoo by the two methods of measurement.

	Dehra Dun-Taungoo
By direct measurement of time of shock	8^m-17^s
By measurement from magnetic disturbances (which eliminates error of clock)	9^m-27^s
or Taungoo time slow	$1^m 10^s$
and mean correction to Taungoo	$+1^m 09^s$

“V. Comparisons of the intervals of time found from Dehra Dun to the other observatories.

Dehra Dun—Barrackpore :—

(i) Direct measurement	5^m-3^s	} 5^m-04^s <i>mean</i>
(ii) By measurement from disturbances	$5-5$	

Dehra Dun—Kodaikanal :—

(i) By direct measurement	$10-22$	} $10-18$
(ii) By measurement from disturbances	$10-13$	

This shows that the clock times at Dehra Dun, Barrackpore and Kodaikanal are practically correct.

“VI. Final values of time of principal shock. For the reasons shown in V there is no good reason for not accepting the times given for Dehra Dun, Kodaikanal, and Barrackpore; the only correction is then to add $1^m 08^s$ to the Taungoo time.

The times then become :—

	(Madras Time)	(G.M.T.)
Dehra Dun	6—11—38	= 0—50—38
Barrackpore	6—16—41	= 0—55—41
Kodaikanal	6—22—00	= 1—01—00
Taungoo	6—21—03	= 1—00—03

(iii) *The Probable Time of Earthquake Occurrence at the Origin.* Thus the time of earthquake disturbance as registered by the magnetograph at Dehra Dun was $0^h 50^m 38^s$, G.M.T., the approximate distance of that place from the most central part of the epifocal zone being $1^\circ 45'$, or 195 km. Within such an epicentral distance, the velocity of propagation of the 1st preliminary tremor is probably 5 or 6 km per sec. If we assume the velocity to be 6 km per sec., the time taken by the seismic waves in travelling the distance of 195 km would be about 32 sec. Now, as the magnetograph is not so sensitive as a seismograph, the time moment recorded at Dehra Dun might correspond to the commencement of the principal portion, the duration of the total preliminary tremor being probably some 20 sec. Thus the time of earthquake occurrence at the epicentre may approximately be taken as $0^h 50^m 38^s$ minus about 50 sec., or

$$t_0 = 0^h 49^m 48^s \text{ (G. M. T.)}$$

10. *Comparison of Magnetic and Seismographic Records.*

(i) According to the Milne horizontal pendulum seismogram at Calcutta, the times of commencement of the 1st preliminary tremor and the principal portion were respectively $0^h 52^m 00^s$

and $0^h 55^m 24^s$ G.M.T. But according to the magnetograph record obtained at Barrackpore, which is not far from the above-mentioned place, the earthquake disturbance began first at $0^h 55^m 41^s$.

(ii) At Colaba, Bombay, the times of commencement of the 1st preliminary tremor and the principal portion were, according to the "Colaba" seismograph, $0^h 53^m 08^s$ and $0^h 56^m 39^s$, respectively. The times of the earthquake disturbance indicated by the magnetographs were as follows:—

{	H. F. Magnetograph,	$0^h 56^m 44^s$
	D. ,, ,	0 57 14
	V. F. ,, ,	0 57 14
Mean.....		0 57 04

The commencement of the disturbance registered by the barograph was $0^h 56^m 44^s$, being practically identical with that indicated by the magnetographs.

(iii) The times of commencement of the earthquake motion at Kodaikanal were as follows:—

Milne Hor. Pend.....	{ Commencement of 1st Prel. Trem.,	$0^h 55^m 48^s$
	,, Princ. Port.,	0 59 43
Magnetograph		1 01 00

From the preceding comparisons, it will be seen that the disturbances recorded by the different magnetographs were nearly simultaneous with the principal portion in the seismograms.

(iv) The commencement of the disturbance in the Taungoo magnetograph, which happened at $1^h 00^m 03^s$, must also evidently be that of the principal portion.

The above magnetograph observations may be divided into two groups, according to the epicentral distances, as follows:—

Group.	Place.	Epicentral Distance.	Time of Commencement.	Time interval required by radial propagation.
<i>A</i>	Barrackpore.	13° 32'	0 ^h 55 ^m 41 ^s	5 ^m 53 ^s
	Bombay.	13 28	0 57 04	7 16
	<i>Mean</i>	13 30	0 56 23	6 35
<i>B</i>	Kodaikanal.	21° 35'	1 ^h 01 ^m 00 ^s	11 ^m 12 ^s
	Taungoo	21 44	1 00 03	10 15
	<i>Mean</i>	21 40	1 00 32	10 44

The “direct method” calculation† gives the following values of the transit velocity :—

{ Group (<i>A</i>)	3.80 km per sec.
{ Group (<i>B</i>)	3.73 „
<i>Mean</i>	3.77 „

This approximately corresponds to the transit velocity of the 1st phase of the principal portion. The “difference method” calculation† gives :—

$$\text{velocity} = 3.65 \text{ km per sec.}$$

11. Analysis of Seismograms. The seismograms which I have analysed were nearly 70 in number, and related to the following 51 stations :—*Tōkyō* (*Hongō*, *Hitotsubashi*, and *Central Meteorological Observatory*); *Mizusawa*; *Ōsaka*; *Kōbe*; *Tadotsu*; *Taihoku*; *Taichu*; *Tainan*; *Dehra Dun**; *Barrackpore**; *Bombay* (*Colaba*); *Taungoo**; *Calcutta* (*Alipore*); *Kodaikanal*; *Shanghai* (*Zikawei*); *Batavia*; *Manila*; *Laibach*; *Pola*; *Triest*; *O'-Gyalla*; *Florence* (*Ximeniano*; *Querce*; and *Quarto Castello*); *Ischia*; *Rocca di Papa*;

† See the *Bull. Imp. Earthquake Inv. Comm.*, Vol. I, No. 1.

* For those stations marked with asterisks, we have only magnetograph records of the earthquake.

Potsdam ; Strassburg ; Göttingen ; Leipzig ; Upsala ; Birmingham ; Shide ; Kew ; Liverpool (Bidston) ; Edinburgh ; Paisley ; San Fernando ; Mauritius ; Cape of Good Hope ; Toronto ; Victoria, B.C. ; Baltimore ; Washington ; Cheltenham ; Tacubaya ; Wellington ; Christchurch ; Rio de Janeiro.*

All the analyses have been made on the supposition that the vibrations recorded represent the movements of a particle of the ground, which are either rectilinear or curvilinear, but which can be resolved into horizontal and vertical components, and not the effects due to the tilting or inclination of the ground ; that is to say, the range of motion has been obtained in each case by dividing the actual trace on the seismogram by the multiplication ratio of the pointer of the instrument. (See the *Publications*, No. 5.)

The elements of the earthquake motion relating to the following 21 stations, from which I did not get copies of the seismograms, have been taken from various monthly, weekly, and other seismological reports :—*Tashkent ; Tiflis ; Achalkalaki ; Batum ; Borshom ; Derbent ; Schemacha ; Jurjew ; Nikolajew ; Irkutsk ; Apia* (Samoa) ; *Vieques* (Porto Rico) ; *Honolulu ; Bairut* (Syria) ; *Ponta Delgada* (Azores) ; *Belgrade ; Krakau ; Jena ; Hamburg ; Padova* † ; *Messina.*

In the descriptions of the seismograms given in the succeeding chapters, the times are, unless otherwise stated, always given in the Greenwich Mean Civil Time. The symbols $2a$ and T denote respectively the range of motion (double amplitude) and the complete period of seismic vibration ; a displacement, which is to be regarded as a single amplitude, being denoted by a .

* The photographic reproduction of the Strassburg registers were too faint, and I was not able to analyse them.

† The copy of the Padova seismogram had unfortunately neither time marking nor scale of magnitude, so that I have taken the elements of motion from the seismological bulletin issued by Prof. Vicentini.

The seismograms obtained at the different stations have been given in Pls. I to XXII of the *Publications*, No. 23.

Chapter II. Open or large time-scale Diagrams of the Kangra Earthquake, furnished by mechanically or photographically registering instruments.

12. List of the Seismograms. The diagrams described in this chapter are those registered either mechanically or photographically by the different seismographs, whose record-receiver moved at a sufficiently high rate, enabling us to measure the amplitude and period of the individual vibrations. The following is the list of the seismograms which I have examined

- (1) Hongō, Tōkyō : EW Component.
- (2) „ „ : NS „
- (3) „ „ : Vertical „
- (4) Hitotsubashi, „ : EW „
- (5) Hongō, „ : EW „ (Tromometer Record).
- (6) Central Met. Observatory, Tokyo : EW Component. („).
- (7) Ōsaka : EW Component.
- (8) Kōbe : NS „
- (9) Tadotsu : EW „
- (10) Taihoku : „ „
- (11) Taichu : „ „
- (12) Tainan : „ „
- (13) O'Gyalla : EW and NS Components.
- (14) Birmingham : EW Component.

- | | | | |
|------|-----------------|---|-------------------------------------|
| (15) | Washington | : | NS Component. |
| (16) | Cheltenham | : | EW „ |
| (17) | „ | : | NS „ |
| (18) | Tacubaya | : | EW „ |
| (19) | „ | : | NS „ |
| (20) | Quarto-Castello | : | EW „ |
| (21) | „ | : | NS „ |
| (22) | Ximeniano | : | Horizontal and Vertical Components. |
| (23) | Ischia | : | NS and EW Components. |
| (24) | Laibach | : | Horizontal and Vertical Components. |
| (25) | Pola | : | NS and EW Components. |
| (26) | Triest | : | Horizontal and Vertical Components. |
| (27) | Manila | : | Horizontal Components. |
| (28) | Rocca di papa | : | „ „ |
| (29) | Colaba | : | Horizontal and Vertical Components. |
| (30) | Potsdam | : | EW Component. |
| (31) | „ | : | NS „ |
| (32) | Göttingen | : | EW „ |
| (33) | „ | : | NS „ |
| (34) | Leipzig | : | EW „ |
| (35) | „ | : | NS „ |
| (36) | Upsala | : | NS „ |
| (37) | „ | : | EW „ |
| (38) | Batavia | : | EW „ |
| (39) | Shanghai | : | EW „ |
| (40) | Rio de Janeiro | : | EW „ |
| (41) | Strassburg. | | |

To the detailed accounts relating to the above mentioned seismograms, (the three last ones excepted), are added short statements of the elements of motion at the following stations :—

pendulum tromometer at the Central Meteorological Observatory, so that the number of the teleseismic records in Tokyo was altogether seven. The 5 better ones of these are described in detail in the succeeding §§. All the instruments at Hongō are set up in the brick "Earthquake-proof House."*

14. *EW Component at Hongō, Tokyo.* (See Pl. I, the *Publications*, No. 23.) The record was furnished by a long-period Omori Horizontal Pendulum (*C-Apparatus*, described in the *Publications*, No. 5), whose constants were as follows:—

Vertical distance between the point of suspension and the point of support = 2.65 metres.

Length of the strut, or the horizontal distance between the centre of the heavy bob and the point of support = 1 metre.

Weight of the heavy bob = 17.4 kg.

Multiplication of the pointer = 15.

Oscillation period of the horizontal pendulum = 61.5 sec.

This seismograph and all the other teleseismic instruments in use in Japan have no damping arrangement. The ground at Hongō is 19 m above the sea level and consists of hard loam.

1st Preliminary Tremor lasted 7^m 17^s, and began with a maximum vibration, whose two displacements were as follows:—

$$\left\{ \begin{array}{l} \text{1st motion} \dots a = 0.37 \text{ mm, towards W;} \\ \text{2nd motion} \dots 2a = 0.57 \text{ mm, } \quad \quad \text{E;} \end{array} \right.$$

Another maximum $2a = 0.57$ mm. $T = 24.7$ sec., occurred 2^m 48^s after the commencement. During the first 4^m, the prevailing period was 4.6 sec. (max. $2a = 0.20$ mm); while, during the remainder of this section, it was 8.0 sec. (max. $2a = 0.30$ mm). There were also some traces of slow vibrations.

2nd Preliminary Tremor lasted 7^m 41^s, and began with a

* A description of this Observatory has been given in the Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. XI.

well defined vibration of $T=36.4$ sec., whose two displacements were as follows:—

$$\begin{cases} \text{1st motion} \dots\dots a=0.83 \text{ mm, towards W;} \\ \text{2nd} \quad \text{,,} \quad \dots\dots 2a=2.5 \quad \text{,,} \quad \text{,,} \quad \text{E;} \end{cases}$$

The next vibration, which was the maximum in this section, was as follows:—

$$T=49.7 \text{ sec.} \begin{cases} \text{1st motion} \dots\dots 2a=4.8 \text{ mm, towards W.} \\ \text{2nd} \quad \text{,,} \quad \dots\dots 2a=5.8 \quad \text{,,} \quad \text{,,} \quad \text{E.} \end{cases}$$

Then there followed 2 large decreasing vibrations of $T=54$ sec. The next vibration ($2a=2.27$ mm) was very slow, $T=86$ sec.; there being also some traces of smaller movements. For the next 54 sec., there were 3 displacements as follows:—

$$\begin{cases} \text{1st motion} \dots\dots 2a=4.1 \text{ mm, towards W;} \\ \text{2nd} \quad \text{,,} \quad \dots\dots 2a=4.5 \quad \text{,,} \quad \text{,,} \quad \text{E;} \\ \text{3rd} \quad \text{,,} \quad \dots\dots 2a=2.7 \quad \text{,,} \quad \text{,,} \quad \text{W;} \end{cases}$$

the first 2 displacements constituting a vibration of $T=37.7$ sec. For the next 47.8 sec., the motion was much smaller and nearly uniform:— $2a=0.97$ mm, $T=26.5$ sec.; there being also some small vibrations of $T=9.0$ sec.

Principal Portion. The commencement of the principal portion was not well marked, and indicated only by the presence of one and half vibrations of $T=59$ sec., which together lasted $1^m 38^s$; the 1st displacement (max.) being $2a=1.3$ mm. These were mixed with small well defined vibrations of $2a=0.33$ mm, $T=11.3$ sec.

For the next $4^m 50^s$, there appeared *proper oscillations* of the pendulum of $T=53$ sec.; the range of motion of the first nine displacements, which were specially large, being as follows: 1.96 mm (towards E); 4.4; 6.47; 6.88; 8.68; 9.8; 10.8; 10.7; 6.74 mm. The last displacement of this epoch was 1.94 mm, towards W.

Then the period became shorter, and for the next $1^m 50^s.4$, there were 4 well defined vibrations of $T=27.6$ sec.; the very first motion being 4.07 mm, towards E. The 1st displacement of the 3rd vibration, which had a maximum $2a$ of 6.24 mm, occurred $1^m 0^s$ after the commencement of this section.

Thereafter the period again quickened, and for the next $1^m 7^s$, the motion consisted of 4 regular vibrations of $T=16.8$ sec., $2a=2.4$ mm.

For the next $1^m 22^s$, these were 8 well defined vibrations of $T=10.3$ sec., (more or less distinctly grouped into 4 slower movements of $T=20.5$ sec.); the $2a$'s of 1st and 8th vibrations, which were the greatest, being respectively 3.67 and 3.57 mm.

For the next $8^m 39^s$, the motion became much smaller, but remained very nearly constant; and the two greatest vibrations of $2a=1.54$ mm and $2a=1.4$ mm occurred respectively at the commencement and end of this phase; $T=11.3$ sec.

For the next $8^m 15^s$, the motion became again smaller:—

$$\text{max. } 2a=0.8 \text{ mm; } T=11.3 \text{ sec.}$$

For the next $7^m 42^s$, the motion was as follows:—

$$\text{max. } 2a=0.72 \text{ mm; } T=12.8 \text{ sec.}$$

End Portion and W_2 and W_3 Vibrations. The average periods deduced from 7 successive groups, each of 50 vibrations, during the first $80^m 57^s$, were as follows:—

- (1) During 1st $10^m 00^s$, $T=12.0$ sec.
- (2) „ next 11 12 , „ 13.4
- (3) „ „ 10 52 , „ 13.0
- (4) „ „ 11 35 , „ 13.9
- (5) „ „ 11 58 , „ 14.3
- (6) „ „ 12 00 , „ 14.4
- (7) „ „ 13 20 , „ 16.0

For the next 4^m 42^s, the motion consisted of slow vibrations.

The subsequent portion may be regarded as belonging to the earthquake motion propagated along the *major arc* of the earth between India and Japan, and consisted at first of vibrations of $T=30$ sec., $2a=0.067$ mm; there being also some slower as well as quicker movements. After 9^m 23^s, the motion became regular and very distinct (marked W_2 in the diagram, Pl. I, the *Publications*, No. 23), and consisted, during the next 6^m 28^s, of vibrations of $T=24.3$ sec., whose max. $2a$ was 0.13 mm; the movements being larger during the first 3^m 39^s.

During the next 2^m 38^s, the motion was smaller; $T=22.1$ sec.

During the next 7^m 5^s, the motion became again quite distinct:—

$$T=19.4 \text{ sec.}, 2a=0.19 \text{ mm.}$$

Thereafter the motion became smaller, the average periods deduced from 3 successive series, each of 50 vibrations, being as follows:—

- (1) During 1st 15^m 14^s, $T=18.2$ sec.
- (2) „ next 13 55 „ „ 16.7 „
- (3) „ „ 14 00 „ „ 16.8 „

These vibrations were divided more or less distinctly into a number of successive maxima, which occurred at an average interval of 7^m 30^s.

Then there followed 3 slight slow vibrations of $T=44$ sec., which may correspond to the W_3 motion, or the repetition of the earthquake first propagated along the *minor arc* of the earth between India and Japan. The succeeding vibrations had an average T of about 20.5 sec.

15. NS Component at Hongō, Tokyo. (See Pl. II, the *Publications*, No. 23.) The record was furnished by a long-period

Omori Horizontal Pendulum, whose construction was similar to that of the EW Component apparatus (§14), and whose instrumental constants were as follows :—

Vertical distance between the point of suspension and the point of support = 2.65 metres.

Length of the strut = 1 metre.

Weight of the heavy bob = 46.0 kg.

Multiplication of the pointer = 20.

Oscillation period of the pendulum = 48.5 sec.

1st Preliminary Tremor lasted 7^m 6^s, and began sharply with a slow vibration, whose two displacements were as follows :—

$$\begin{cases} \text{1st motion} \dots a = 0.17 \text{ mm, towards N;} \\ \text{2nd } \text{,,} \dots 2a = 0.28 \text{ } \text{,,} \text{, } \text{,,} \text{ S;} \end{cases}$$

the vibration being mixed with small movements, whose very 1st displacement was $a = 0.07$ mm, towards N.

The motion was larger (max. $2a = 0.43$ mm) and nearly constant during the first 4^m 28^s of this phase, consisting of vibrations as follows :—

$$\begin{cases} \text{For the 1st 2}^{\text{m}} 29^{\text{s}} : T = 29.8 \text{ sec.} \\ \text{,, } \text{,, next 1}^{\text{m}} 59^{\text{s}} : \text{,,} = 20.0 \text{ } \text{,,} \end{cases}$$

During the remaining 2^m 38^s, the motion was small :—

$$T = 15.8^{\text{sec.}}, \quad 2a = 0.22^{\text{mm}}.$$

Throughout this phase, there were superpositions of small well defined vibrations of $T = 5.2$ sec., $2a = 0.14$ mm.

2nd Preliminary Tremor lasted about 8^m 20^s. During the first 2^m 0^s, the motion was large and consisted of 3 vibrations made up of the following six displacements :—

- (1) $a = 0.55$ mm, towards N,
- (2) $a = 2.33$, , S, $\dots \frac{1}{2} \times T = 11.6$ sec.
- (3) $2a = 3.95$, , N, } $\dots T = 46.2$ sec.
- (4) $2a = 3.8$, , S, }

$$\left. \begin{array}{l} (5) \quad 2a=3.45 \text{ mm, towards N,} \\ (6) \quad 2a=2.73 \quad , \quad , \quad \text{S,} \end{array} \right\} \dots\dots\dots T=46.2 \text{ sec.}$$

For the next 2^m 3^s, the motion was small and consisted of 3 vibrations, of which the first had a $T=55.2$ sec., and the last two an average $T=33.5$ sec.; the 2nd vibration having the max. $2a$ of 1.63 mm.

For the next 4^m 22^s, the motion was larger and nearly constant, and consisted of 6 vibrations of $T=43.7$ sec.; the initial motion being $a=1.75$ mm, towards N. The 2nd and 3rd displacements formed a vibration of $T=40.4$ sec.; the 3rd vibration having the max. $2a$ of 3.53 mm.

Principal Portion. The first 1^m 25^s was made up of 2 slow vibrations of $T=42.5$ sec. The next vibrations was still greater and the recording pointer of the instrument went out of the smoked paper.

3^m 28^s later, at 1^h 20^m 19^s, the pointer again entered on the smoked paper; the motion being, for the next 55 sec., greater than 8.3 mm. For the next 4^m 23^s, the diagram showed still large pendulum oscillations, which were nearly constant:—max. $2a=6.65$ mm, $T=47.8$ sec. For the next 1^m 25^s there were 2 smaller vibrations:—max. $2a=2.7$ mm, $T=42.5$ sec.

For the next 4^m 27^s, the motion was nearly uniform and consisted essentially of vibrations of $T=10.3$ sec., max. $2a=1.7$ mm; there being also some traces of slower movements of $T=\text{about } 23$ sec. For the next 3^m 58^s, the motion consisted of 21 well defined vibrations of $T=11.2$ sec., max. $2a=1.4$ mm. For the next 4^m 57^s, the motion consisted chiefly of the vibrations of $T=19.5$ sec., max. $2a=1.3$ mm; there being, towards the end of this epoch, movements of $T=10.4$ sec., max. $2a=1.2$ mm. For the next 7^m 35^s, the motion was much smaller, but nearly constant:—

$T=10.9$ sec., $2a=0.68$ mm. For the next $10^m 0^s$, the motion was slightly smaller :— $T=22.6$ sec., max. $2a=0.58$ mm.

End Portion and W_2 Vibrations. For the first $11^m 14^s$, the motion was nearly constant :— $T=12.5$ sec., max. $2a=0.3$ mm. For the next $33^m 32^s$, the motion was again slightly smaller, but nearly constant, (max. $2a=0.2$ mm), the average period deduced from three successive series of 50 vibrations being as follows :—

$$\left. \begin{array}{l} T=12.9 \text{ sec.} \\ 12.7 \\ 13.5 \end{array} \right\} \dots\dots\dots \text{Mean, } 13.0 \text{ sec.}$$

In some places these vibrations were mixed with slower ones of $T=26.2$ sec.

Then, at $2^h 43^m 37^s$ there appeared three slow vibrations of $T=45$ sec., which lasted together $2^m 15^s$, (max. $2a=0.1$ mm); there being also a superposition of smaller movements of $T=11.9$ sec. These vibrations may belong to the earthquake motion propagated along the *major arc* of the earth. The subsequent vibrations gradually diminished, the period being as follows :—

$$\left\{ \begin{array}{l} \text{for the 1st } 3^m 51^s : T=21.0 \text{ sec. :} \\ \quad \text{,, next 4 } 48 : \text{,, } =17.0 \text{ ,, ;} \\ \quad \text{,, } \quad \text{,, } 7 \quad 25 : \text{,, } =19.4 \text{ ,, .} \end{array} \right.$$

There were also small vibrations of $T=12.6$ sec.

The distinct commencement of the W_2 motion occurred at $3^h 21^m 17^s$. $4^m 0^s$ later on, the motion became larger and well defined, as follows :—

For the 1st $2^m 45^s$:— $T=25.4$ sec., max. $2a=0.1$ mm.

For the next $12^m 46^s$, the motion became quicker, the T during the earlier $8^m 28^s$ being 20.7 sec. During the remaining $4^m 14^s$ of this epoch, which formed the most active part of the

W_2 motion, the T was = 19.5 sec.; max. $2a$ of 0.12 mm occurring at the commencement.

For the next 5^m 13^s, the motion was small:— T = about 19.0 sec. For the next 8^m 42^s, the motion became again larger:— T = 17.4 sec., $2a$ = 0.09 mm. For the next 1^m 58^s, the motion was small, T being 16.9 sec. For the next 2^m 57^s, the motion was also small, but slower:— T = 29.5 sec. (?) For the next 6^m 56^s, the motion became again active:— T = 20.8 sec., $2a$ = 0.05 mm.

The period of the subsequent vibrations was as follows:—

$$\left\{ \begin{array}{l} \text{During the 1st 4}^m 46^s: T = 26.1 \text{ sec.}; \\ \text{,, next 2 32: ,, = 16.9 ,,}; \\ \text{,, ,, 22 42: ,, = 17.7 ,,}; \\ \text{,, ,, 14 22: ,, = 19.6 ,,}. \end{array} \right.$$

16. Vertical Component at Hongō, Tokyo. (See Pl. III, the *Publications*, No. 23.) The diagram was furnished by a continuous vertical motion recorder, which is essentially a Gray-Ewing type seismograph, with some modifications for reducing the friction between its different parts. The instrumental constants were as follows:—

Length of the vertical spiral springs = 1.2 metres.

Horizontal distance between the centre of the steady mass
and the pivot = 1.2 metres.

Weight of the heavy bob = 9 kg.

Multiplication of the pointer = 12.

Oscillation Period of the pendulum = 4 sec.

Preliminary Tremors. For the first 12^m 16^s, the motion consisted mostly of pendulum vibrations of T = 4.2 sec.; the two greatest movements of 0.71 and 0.33 mm occurring 12^s and 9^m 2^s respectively after the commencement. The diagram showed alternations of maximum and minimum groups. At 7^m 45^s from the

commencement there were 3 slower vibrations of the following elements :— $T=7.3$ sec., $2a=0.31$ mm.

Thereafter the pendulum oscillations almost disappeared, and for the next $5^m 22^s$ the motion was very small and slow.

Principal Portion. During the first $3^m 46^s$ the motion was regular, having the following elements :— $T=45.2$ sec., $2a=0.07$ mm.

For the next $10^m 39^s$, the motion was most active, as follows :—

- | | | | | | |
|---|-------|----------------|--------------|----------------|---------------|
| { | (i) | During the 1st | $1^m 29^s$; | $T=29.7$ sec., | $2a=0.28$ mm. |
| | (ii) | „ | next 1 07; | „ =22.3 „ , „ | =0.13 |
| | (iii) | „ | „ 2 56; | „ =14.7 „ , „ | =0.29 |
| | (iv) | „ | „ 5 09; | „ =13.4 „ , „ | =0.092. |

The maximum movements of (ii) and (iii) occurred at $1^h 22^m 00^s$ and $1^h 23^m 07^s$, respectively.

End Portion. The motion was small and as follows :—

- | | | | |
|---|----------------|--------------|---------------|
| { | During the 1st | $6^m 12^s$; | $T=11.6$ sec. |
| | „ | next 2 42; | „ =18.0 „ |
| | „ | „ 2 32; | „ =15.2 „ |
| | „ | „ 11 17; | „ =14.4 „ |

Thereafter the motion gradually decreased, being reduced almost to *nil* in the course of the next 30 minutes. Towards the end :— $T=15.4$ sec.

W₂ Motion. At $3^h 33^m 22^s$, there appeared some slight movements. After $4^m 9^s$, the motion became distinct, the average T during the next $3^m 15^s$ being 19.5 sec. This probably indicates the 3rd phase of the principal portion of the W_2 motion.

17. Summary of the Hongō (Tokyo) Observations.

For the sake of convenience I give below tabular statements of the results of analysis contained in the preceding §§; the numerals enclosed within brackets show the order of occurrence of different subdivisions in each phase of motion.

TABLE IV. *EW Component at Hongō.*

Duration.	$T = \left\{ \begin{array}{l} \text{Average} \\ \text{Period.} \end{array} \right.$	Max. $2a$.
[1st Preliminary Tremor. Duration = 7 ^m 17 ^s .]		
(1) 4 ^m 00 ^s	$\left\{ \begin{array}{l} 4.6 \text{ sec.} \dots\dots 0.20 \text{ mm} \\ 24.7 \dots\dots 0.57 \end{array} \right.$	
(2) 3 17	8.0	0.30
[2nd Preliminary Tremor. Duration = 7 ^m 41 ^s .]		
(1) 0 ^m 36.4 ^s	36.4 sec.	2.5 mm
(2) 0 49.7	49.7	5.8
(3) 1 48.0	54.0	
(4) 1 26	86.0	2.27
(5) 0 54	37.7	4.50
(6) 0 47.8	$\left\{ \begin{array}{l} 26.5 \dots\dots 0.97 \\ 9.0 \dots\dots \text{Small.} \end{array} \right.$	
[Principal Portion. Duration = 35 ^m 23 ^s .]		
(1) 1 ^m 38 ^s	$\left\{ \begin{array}{l} 59.0 \text{ sec.} \dots\dots 1.30 \text{ mm} \\ 11.3 \dots\dots 0.33 \end{array} \right.$	
(2) 4 50	53.0	10.8 (pendulum oscillations)
(3) 1 50	27.6	6.24
(4) 1 7	16.8	2.4
(5) 1 22	$\left\{ \begin{array}{l} 10.3 \dots\dots 3.67 \\ 20.5 \dots\dots - \end{array} \right.$	
(6) 8 39	11.3	1.54
(7) 8 15	11.3	0.80
(8) 7 42	12.8	0.72
[End Portion.]		
(1) 80 ^m 57 ^s	13.6 sec.	Small.
(2) 4 42	—	"

Duration.	$T = \left\{ \begin{array}{l} \text{Average} \\ \text{Period.} \end{array} \right.$	Max. $2a$.
[W_2 Motion.]		
(1) 9 ^m 23 ^s	30.0 sec.	0.067 mm
(2) 6 28	24.3	0.13
(3) 2 38	22.1	Small.
(4) 7 5	19.4	0.19
(5) 43 9	17.2	Small.
[W_3 Motion.]		
(1) 2 ^m 12 ^s	44.0	Small.
(2) —	20.5	„

TABLE V. *NS Component at Hongō.*[1st Preliminary Tremor. Duration = 7^m 6^s.]

(1) 2 ^m 29 ^s	29.8 sec.	} 0.43 mm
(2) 1 59	20.0	
(3) 2 38	15.8	0.22
Mixed throughout	5.2	0.14

[2nd Preliminary Tremor. Duration = 8^m 20^s.]

(1) 2 ^m 0 ^s	{ 23.1 sec.	2.33 mm
	{ 46.2	3.95
(2) 2 3	{ 55.2	—
	{ 33.5	1.63
(3) 4 22	{ 40.4	3.53
	{ 44.4	

Duration.	$T = \begin{cases} \text{Average} \\ \text{Period.} \end{cases}$	Max. $2a$.
[Principal Portion. Duration = 42 ^m 33 ^s .]		
(1) 1 ^m 25 ^s	42.5 sec.	
(2) 4 23	(Motion large, pointer went out.)	
(3) 4 23	47.8 (pend. oscil.)	6.65
(4) 1 25	42.5	2.7
(5) 4 27	$\begin{cases} 10.3 \dots\dots\dots 1.7 \\ 23. \end{cases}$	
(6) 3 58	11.2	1.4
(7) 4 57	$\begin{cases} 19.5 \dots\dots\dots 1.3 \\ 10.4 \dots\dots\dots 1.2 \end{cases}$	
(8) 7 35	10.9	0.68
(9) 10 00	22.6	0.58
[End Portion.]		
(1) 11 ^m 14 ^s	12.5 sec	0.3 mm
(2) 33 32	$\begin{cases} 13.0 \dots\dots\dots 0.2 \\ 26.2 \end{cases}$	
[W ₂ Motion.]		
(1) 2 ^m 15 ^s	$\begin{cases} 45.0 \text{ sec.} \dots\dots\dots 0.1 \text{ mm} \\ 11.9 \dots\dots\dots - \end{cases}$	
(2) 16 4	$\begin{cases} 19.1 \dots\dots\dots (\text{Small.}) \\ 12.6 \dots\dots\dots \end{cases}$	
(3) 19 21	—	(Small.)
(4) 4 0	—	"
(5) 2 45	25.4	0.1
(6) 8 28	20.7	
(7) 4 14	19.5	0.12
(8) 5 13	19.0	(Small.)
(9) 8 42	17.4	0.09

Duration.	$T = \begin{cases} \text{Average} \\ \text{Period.} \end{cases}$	Max. $2a$.
[W_2 Motion.]		
(10) 1 58	16.9	(Small.)
(11) 2 57	29.5	"
(12) 6 56	20.8	0.05
(13) 4 46	26.1	(Small.)
(14) 39 36	18.1	"

TABLE VI. *Vertical Component at Hongō.*

[Preliminary Tremors.]		
(1) 12 ^m 16 ^s	$\begin{cases} 4.2 \text{ sec. (pend. oscil.)} & \dots 0.71 \text{ mm} \\ 7.3 & \dots 0.31 \end{cases}$	
(2) 5 22	—	(Small.)
[Principal Portion.]		
(1) 3 ^m 46 ^s	45.2 sec.	0.07 mm
(2) 1 29	29.7	0.28
(3) 1 07	22.3	0.13
(4) 2 56	15.7	0.29
(5) 5 09	13.4	0.092
[End Portion.]		
(1) 6 ^m 12 ^s	11.6 sec.	(Small.)
(2) 16 31	15.9	"
(3) 30	15.4	"
[W_2 Motion]		
Commencement at 3 ^h 33 ^m 22 ^s		
(1) 4 ^m 09 ^s	—	(Small.)
(2) 3 15	19.5 sec	"

18. *EW Component at Hitotsubashi, Tōkyō.* The diagram was furnished by Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows :—

Vertical distance between the point of suspension
and the point of support = 0.75 metre.

Length of strut = 0.75 metre.

Weight of the heavy bob = 6.4 kg.

Multiplication of the pointer = 8.

Oscillation period of the pendulum = 31.1 sec.

At Hitotsubashi, the ground is low and very soft.

1st Preliminary Tremor. Duration = 7^m 32^s. The motion was very nearly constant in amplitude :— $T = 4.6$ sec., $2a = 0.44$ mm. ; there being also ill-defined traces of two sets of slower movements of $T =$ about 7.2 and 15.7 sec., respectively.

During the earlier one-third of this phase, the motion was mixed up with very small movements of the *macro-seismic character*, of $T = 0.71$ sec.

19. *Tromometer Records.* The earthquake was also recorded by two Omori Horizontal Pendulum Tromometers* set up at the Seismological Institute (Hongō) and at the Central Meteorological Observatory ; the two instruments, whose magnifications were 120 and 87 times respectively, being in other respects exactly similar to one another, as follows :—

Weight of the heavy bob = 50 kg.

Vertical distance between the point of support and
the point of suspension = 1 metre.

Length of the strut = 20 cm.

Total length between the point of support and the
writing index = 120 cm.

The natural oscillation period of the pendulums at the Seismological

* These instruments are described in the *Publications*, No 12.

- $$\left\{ \begin{array}{l} \text{(i) During the 1st } 1^{\text{m}} 56^{\text{s}} : 4 \text{ vibrations of } T=29.0 \text{ sec. ;} \\ \qquad \qquad \qquad 2a=0.66 \text{ mm (last but two vibr.).} \\ \text{(ii) During the next } 2^{\text{m}} 27^{\text{s}} : 4 \text{ vibrations of } T=38.5 \text{ sec. ;} \\ \qquad \qquad \qquad 2a=0.58 \text{ mm.} \end{array} \right.$$

In the last $3^{\text{m}} 17^{\text{s}}$ of this phase, the motion remained very nearly constant in amplitude; there being also vibrations of $T=9.1$ sec., $2a=0.25$ mm.

3rd Phase, Principal Portion. Duration, about $9^{\text{m}} 40^{\text{s}}$. The motion began with a sudden large displacement of $a=0.97$ mm, towards W. The counter motion, towards E, was still larger, and the recording pointer strack against the side supports, the vibrations remaining active throughout this phase.

The principal vibrations had an average T of 34.8 sec., the amplitude being very large. There were also large movements of $T=21$ sec., which were probably due to pendulum oscillations.

4th, etc. Phases, Principal Portion. The motion became quicker in period, the amplitude remaining on the whole nearly constant for the next $11^{\text{m}} 36^{\text{s}}$:—

- $$\left\{ \begin{array}{l} \text{(i) At the commencement :— } T=12.6 \text{ sec., } 2a=1.67 \text{ mm.} \\ \text{(ii) Towards the end :— } T=12.0 \text{ sec., } 2a=1.25 \text{ mm.} \end{array} \right.$$

The motion consisted of a series of alternations of maximum and minimum groups of vibrations; each maximum group beginning with a sudden displacement towards E, followed by a much larger counter motion towards W, as shown below :—

<i>Motion towards E.</i>			<i>Motion towards W.</i>		
<i>1st Group.</i>	1st displacement,	0.17 mm ;	2nd displacement,	0.21 mm ;	
	3rd	0.61 ;	4th	1.18 ;	
	5th	1.41 ;	6th	1.09 ;	
	7th	0.72 .			

2nd Group.	{ 1st displacement, . . 0.22 mm ; 2nd displacement, . . 0.40 mm ;	
	3rd „ 0.57 ; 4th „ 1.05 ;	
	5th „ 1.28 ; 6th „ 1.08 ;	
	7th „ 1.03 .	
3rd Group.	{ 1st displacement, . . 0.76 mm ; 2nd displacement, . . 1.53 mm ;	
	3rd „ 1.67 ; (Pointer ran out)	
4th Group.	{ 1st displacement, . . 0.14 mm ; 2nd displacement, . . 0.32 mm ;	
	3rd „ 0.68 ; 4th „ 0.97 ;	
	5th „ 0.92 ; 6th „ 0.77 .	

In the minimum groups, there were also quicker vibrations :— $T=8.2$ sec., $2a=0.24$ mm.

For the next 6^m 54^s, the motion became much smaller :— $T=11.8$ sec., $2a=0.58$ mm.

Thereafter the motion became again abruptly much smaller.

Pulsatory Oscillations. On April 4th, there existed slight but distinct pulsatory oscillations, whose elements of motion, before and after the earthquake, were as follows :—

$$\left\{ \begin{array}{l} \text{Before the eqke: } T=4.1 \text{ sec., } 2a=0.012 \text{ mm.} \\ \text{After the eqke: } „=4.1 \text{ „, „=0.011 „.} \end{array} \right.$$

The result of the analysis given above are summarized in the following table :—

TABLE VII. *EW Tromometer Record at Hongō.*

Duration.	$T = \left\{ \begin{array}{l} \text{Average} \\ \text{Period.} \end{array} \right.$	Max. $2a$.
[1st Preliminary Tremor. Duration=7 ^m 27 ^s]		
	$\left\{ \begin{array}{l} 8.6 \text{ sec.} \\ 4.4 \\ 2.2 \end{array} \right.$	$\left\{ \begin{array}{l} 0.33 \text{ mm} \\ 0.25 \\ (\text{Small.}) \end{array} \right.$

Duration	$T = \begin{cases} \text{Average} \\ \text{Period.} \end{cases}$	Max. $2a$.
[2nd Preliminary Tremor. Duration = 7 ^m 21 ^s]		
	$\left\{ \begin{array}{l} 11.8 \text{ sec.} \\ 8.8 \\ 4.8 \end{array} \right.$	$\begin{array}{l} 1.05 \text{ mm} \\ 0.61 \\ 0.21 \end{array}$
[1st and 2nd Phases, Principal Portion. Duration = 7 ^m 21 ^s]		
(1) 3 ^m 3 ^s	$\left\{ \begin{array}{l} 9.4 \text{ sec.} \\ 16.8 \\ 53.0 (?) \end{array} \right.$	$\begin{array}{l} 0.40 \text{ mm} \\ 0.53 \\ 0.36 \end{array}$
(2) 1 56	29.0	0.66
(3) 2 27	38.5	0.58
In (2) and (3)	9.1	0.25
[3rd Phase, Principal Portion. Duration = 9 ^m 40 ^s].		
	$\left\{ \begin{array}{l} 34.8 \text{ sec.} \\ 21.0 \text{ (pend. oscil.)} \end{array} \right.$	$\begin{array}{l} (\text{Large.}) \\ , , \end{array}$
[4th, etc. Phases, Principal Portion.]		
(1) 11 ^m 36 ^s	$\left\{ \begin{array}{l} 12.3 \text{ sec.} \\ 8.2 \end{array} \right.$	$\begin{array}{l} 1.67 \text{ mm} \\ 0.24 \end{array}$
(2) 6 54	11.8	0.58

21. Tromometer Record obtained at the Central Meteorological Observatory, Tokyo. The record is very imperfect, as the natural oscillation period of the pendulum was too short.

1st Preliminary Tremor. Duration = 7^m 30^s. The motion, which was much smaller during the last 3^m 12^s of this phase, consisted of the following two sets of vibrations:—(i) $T = 4.4$ sec., $2a = 0.17$ mm; (ii) $T = 7.4$ sec., $2a = 0.22$ mm,

2nd Preliminary Tremor. Duration = 7^m 23^s. The motion was much greater than in the preceding phase, and consisted of large pendulum oscillations of $T=9.1$ sec., whose maximum vibration ($2a=1.06$ mm) was the 6th in the maximum group occurring at the commencement. There were also some doubtful traces of slow vibrations.

1st and 2nd Phases, Principal Portion. Duration = 7^m 17^s. There were more or less definite traces of slow vibrations:— $T=36.8$ sec., $2a=0.20$ mm, these being mixed with pendulum oscillations of $T=8.1$ sec. (max. $2a=0.23$ mm).

3rd Phase, Principal Portion. Duration = 8^m 0^s. For the first 2^m 9^s, the motion was comparatively small, and made up of two slow vibrations of $T=23.8$ sec., followed by pendulum oscillations of $T=9.0$ sec. (max. $2a=1.4$ mm). During the remaining part of this phase, the pendulum oscillation attained its full activity (max. $2a=2.9$ mm): $T=11.0$ sec.

4th, etc. Phases, Principal Portion. The motion became smaller, and consisted during the next 4^m 49^s of the following vibrations:— $T=10.3$ sec., $2a=2.2$ mm; the vibrations being divided into 3 successive maximum groups, which occurred at an average interval of 1^m 36^s. There were also some slower movements of T =about 15.2 sec. (max. $2a=0.78$ mm).

Then the motion became much smaller and remained nearly constant for the next 6^m 2^s:— $T=11.6$ sec., $2a=0.48$ mm. During the next 7^m 36^s, the motion was again smaller:— $T=11.4$ sec., $2a=0.12$ mm. Thereafter the motion became still smaller.

Pulsatory Oscillations. The average period of the pulsatory oscillations, measured after the earthquake, was 4.14 sec.

22. Ōsaka, Japan. EW Component. (See Pl. VI, the

Publications, No. 23.) The Meteorological Observatory (Director, N. Shimono).

The record was given by an Omori Horizontal Pendulum of portable form, of the following constants :—

Vertical distance between the points of suspension
and of support = 86 cm.
Length of the horizontal strut = 44 cm.
Weight of the heavy bob = 16 kg.
Multiplication of the pointer = 20
Oscillation period of the pendulum = 28 sec.

The Ōsaka Observatory is situated on low soft ground, about 5.3 m above the sea-level.

Time of earthquake occurrence = $0^h 58^m 51^s$. Duration = $3\frac{1}{2}^h$.

1st Preliminary Tremor. Duration = $7^m 12^s$. The motion began with quick vibrations of gradually increasing amplitude, and after 20 sec. there appeared the first slow vibration consisting of the following 2 displacements :—

{ 1st motion, $a = 0.37$ mm, towards W (marked b in the diagram);
{ 2nd „, $2a = 0.70$ „, „ E.

During the first $4^m 0^s$ of this phase the motion consisted of the following 3 sets of vibrations ;—

{ (i) $T = 23.8$ sec., $2a = 1.05$ mm; (iii) $T = 8.5$ sec., (small);
{ (ii) „ = 4.7 „, „ = 0.53 „ ;

there being also traces of still quicker movements.

During the remaining $3^m 12^s$, the motion was much smaller, the vibrations being two-fold, as follows :—

(i) $T = 4.5$ sec., $2a = 0.22$ mm; (ii) $T = 7.8$ sec., $2a =$ small.

2nd Preliminary Tremor. Duration = $6^m 55^s$. The 1st 2 vibrations consisted of the following 4 displacements (marked hi , ji , jk , kl in the diagram) :—

Thereafter the motion decreased gradually and was brought almost to *nil* in the course of the next 30 min.; the period deduced from 3 successive series, each of 50 vibrations, being as follows :—

$$\left. \begin{array}{l} T=14.3 \text{ sec.} \\ 13.7 \\ 14.3 \end{array} \right\} \text{mean, 14.1 sec.}$$

W₂ Motion. At 3^h 22^m 30^s, there appeared some slow movements which for the 1st 1^m 20^s remained indistinct. During the next 5^m 26^s, the motion was still small, but consisted of regular vibrations of $T=25.1$ sec. For the next 5^m 53^s, the motion, which was slightly larger, became decidedly quicker :— $T=20.8$ sec. During the next 3^m 0^s, the period remained unchanged, but the motion became markedly larger :— $T=20.0$ sec., $2a=0.02$ mm. For the next 1^m 31^s, the motion was small; T =about 18.2 sec. (?). For the next 5^m 56^s, the motion was most active :— $T=18.7$ sec., $2a=0.06$ mm; the maximum having occurred at 3^h 40^m 56^s, or 18^m 26^s after the assumed commencement of the *W₂* motion. For the next 5^m the motion was more or less distinct.

W₃ Motion. What may correspond to the *W₃* motion appeared at 4^h 34^m 59^s, the vibrations being as follows :— $T=18.5$ sec., $2a=0.015$ mm.

23. Kobe, Japan. NS Component. (See Pl. VII, the *Publications*, No. 23.) The Meteorological Observatory (Director, G. Nakagawa).

The record was furnished by an Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows :—

Vertical distance between the points of suspension and of
support = 90 cm.

Length of the horizontal strut = 75 cm.

Weight of the heavy bob = 11 kg.

Multiplication of the pointer = 20.

Oscillation period of the pendulum = 27 sec.

The Observatory of Kobe stands on the top of a hill spur 58 m above the sea-level.

The time of earthquake occurrence = $0^h 58^m 26^s$.

1st Preliminary Tremor. Duration = $7^m 0^s$. The motion consisted of small but distinct vibrations of $T = 4.4$ sec., $2a = 0.05$ mm; there being at first some traces of smaller movements. There were also vibrations of $T = 11.5$ sec.

2nd Preliminary Tremor. Duration = $5^m 44^s$ (?). For the first 17 sec., the motion was small, there being an initial northward slow motion mixed with smaller vibrations. Then took place, for the next 62 sec., two large vibrations of $T = 31$ sec. (pendulum oscillations ?), whose successive displacements were as follows:—

1st motion = 1.3 mm, towards S; 2nd motion = 2.6 mm, towards N.

3rd „ = 2.3 „ „ S; 4th „ = 1.5 „ „ N.

For the next $2^m 38^s$, the motion was small and consisted of slow irregular vibrations, mixed with small ones. For the next $1^m 58^s$, the motion consisted of 4 pendulum oscillations of $T = 29.5$ sec.; the 2nd having the max. $2a$ of 3.0 mm.

Principal Portion. For the first $2^m 16^s$, the motion was small:— $T = 34$ sec., $2a = 0.48$ mm. For the next $1^m 59^s$, the motion was larger and consisted of 2 and half slow vibrations:— $T = 55.8$ sec., $2a = 2.0$ mm. For the next $2^m 2^s$, which may correspond to the 2nd phase, the motion became larger and consisted of 3 vibrations:— $T = 40.3$ sec., $2a = 4.8$ mm; the last vibration being

the maximum. For the next $1^m 39^s$, the record consisted of 3 and half large pendulum oscillations :— $T=28.3$ sec., $2a=8.2$ mm. For the next $4^m 30^s$, the motion became smaller, but was still active :— $T=32.0$ sec., $2a=2.7$ mm ; $T=18.5$ sec., $2a=2.0$ mm. For the next $9^m 12^s$, the motion was smaller and nearly constant :— $T=23.5$ sec., $2a=1.1$ mm ; $T=9.4$ sec. For the next $8^m 15^s$, the motion was again smaller and nearly constant :— $T=11.9$ sec., $2a=0.19$ mm ; $T=17.8$ sec., $2a=0.45$ mm.

Thereafter the motion was much smaller, the T deduced from 3 successive series, each of 50 vibrations, being as follows :—

$$\left. \begin{array}{l} 12.9 \text{ sec.} \\ 13.0 \text{ „} \\ 13.4 \text{ „} \end{array} \right\} \text{mean, } 13.1 \text{ sec.}$$

24. Tadotsu, Japan. *EW Component.* The Meteorological Observatory (Director, N. Maeda).

The record was furnished by an Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows :

Vertical distance between the points of suspension
and of support = 85 cm.

Length of the horizontal strut = 75 cm.

Weight of the heavy bob = 10 kg.

Multiplication of the pointer = 20.

Oscillation period of the pendulum. = 28 sec.

The Tadotsu Observatory stands on low ground, about 5.9 m above the sea-level, and only 18 m from the sea beach.

Time of earthquake commencement = $0^h 58^m 49^s$. Duration = $3\frac{1}{2}^s$.

The record is not very satisfactory owing to a great amount of friction in the seismograph.

1st Preliminary Tremor. Duration = $7^m 0^s$. The motion con-

sisted essentially of the P_1 vibrations, mixed with two sets of slower movements, as follows:— $T=4.7$ sec.; $T=10.4$ sec. (?); $T=24.2$ sec., $2a=0.2$ mm (pend. oscil ?). In the latter half of this portion, the motion was very small.

2nd Preliminary Tremor. Duration= $7^m 42^s$. The motion was greater during the first $3^m 48^s$, and the two maximum $2a$'s of 0.86 and 0.62 mm occurred at the commencement and the end of this epoch:— $T=31.5$ sec. During the remaining $3^m 54^s$, the motion was much smaller:— $T=35.6$ sec., $2a=0.14$ mm; $T=14.8$ sec.

Principal Portion. [1st and 2nd phases.] Duration= $5^m 21^s$. During the first 52 sec., the motion was small. Then the motion became larger and consisted of slow vibrations:— $T=39.4$ sec., $2a=1.4$ mm; $T=19$ sec.

[*3rd phase.*] Duration, about $6^m 30^s$. The record consisted of large pendulum oscillations (max. $2a>12.4$ mm) of $T=28$ sec.; the pointer having finally got out of the smoked paper.

For the next 6 m, the motion was much smaller and nearly constant:— $T=10.2$ sec., $2a=0.53$ mm; $T=19.7$ sec., $2a=0.72$ mm. Thereafter the motion became again smaller and very gradually diminished, the motion being as follows:—

$$\left\{ \begin{array}{l} \text{for the 1st } 9^m 28^s: T=12.6 \text{ sec., } 2a=0.27 \text{ mm;} \\ \text{,, next 15 } 10: \text{,,}=13.8 \text{ ,, , ,,}=0.18 \text{ ,,;} \\ \text{towards the end: ,,}=14.3 \text{ ,, , ,,}= \text{Small.} \end{array} \right.$$

These three sets of vibrations give an average period of 13.6 sec.

W_2 Motion. For about 50 min. before the commencement of the W_2 motion, the vibrations were practically *nil*. Time of commencement of $W_2=3^h 31^m 22^s$. For the first $5^m 13^s$, the motion was very small, the earlier part being doubtful. For the next

12^m 25^s, the motion was small, but distinct :— $T=19.5$ sec., $2a=0.045$ mm.

W₃ Motion. Time of commencement = 4^h 24^m 35^s. The motion, indicated for about 3 minutes, consisted of very slight doubtful traces of slow movements of $T=36.3$ sec. (?)

25. Taihoku, Formosa, Japan. *EW Component.* The Meteorological Observatory (Director, H. Kondō).

The record was furnished by an Omori Horizontal Pendulum of portable form, of the following constants :—

Vertical height between the points of suspension and of support = 75 cm.

Length of the horizontal strut = 75 cm.

Weight of the heavy bob = 6½ kg.

Multiplication of the pointer = 10.

Oscillation period of the pendulum = about 14 sec.

The Observatory is situated on soft flat ground, about 9 m above the sea-level.

The motion was recorded evidently with a large amount of friction.

1st Preliminary Tremor. Duration = 6^m 6^s. During the first 3^m 30^s, the motion consisted of the vibrations of $T=4.3$ sec., $2a=0.06$ mm, mixed at first with small macro-seismic movements of $T=1.07$ sec.; $T=2.1$ sec. During the remaining 2^m 36^s, the motion was much smaller and consisted of uniform vibrations of $T=3.3$ sec.

2nd Preliminary Tremor. Duration = 5^m 25^s. The motion consisted essentially of the vibrations of $T=4.5$ sec., $2a=0.1$ mm. At the commencement and end of this phase, however, there were slower vibrations of $T=21$ sec., $2a=0.1$ mm.

Principal Portion. [1st and 2nd phases.] Duration = 4^m 35^s. During the 1st 2^m 24^s, the motion was small and consisted of the following 3 sets of vibrations :— $T=41.2$ sec., $2a=0.22$ mm ; $T=4.4$ sec., $2a=0.08$ mm ; $T=10.8$ sec.

Then there took place a slow vibration of period of 30 sec., as follows :—

$$\left\{ \begin{array}{l} \text{1st displacement.} \quad \dots \quad a=1.7 \text{ mm, towards W;} \\ \text{2nd} \quad \quad \quad \dots \quad 2a=3.1 \text{ ,, ,, ,, E.} \end{array} \right.$$

The subsequent 6 vibrations were very small.

[3rd phase.] Duration = 5^m 30^s. For the first 3^m 29^s, the motion was most active and consisted of 14 vibrations of $T=14.4$ sec. (pendulum oscillations); the last 4 vibrations being particularly great, and the last but three having the maximum recorded range of 11.9 mm. This occurred 2^m 35^s after the commencement of the 3rd phase. During the remaining 2^m 1^s, the motion was much smaller :— $T=11.8$ sec., $2a=2.05$ mm ; $T=5.7$ sec. In the subsequent phases of the principal portion, the vibrations were very small.

End Portion. For the first 10^m 16^s, the motion was very nearly constant, consisting of the following vibrations :— $T=11.6$ sec., $2a=0.35$ mm ; $T=6.6$ sec.; the maximum movement having occurred at the end of this phase. Thereafter the motion gradually diminished, but was more or less distinct for the next 18^m 0^s:— $T=11.5$ sec., $2a=0.1$ mm. The motion was slightly indicated for the next 30^m, when the smoked paper was changed.

26. Taichu, Formosa, Japan. *EW Component.* (See Pl. VIII, the *Publications*, No. 23.) The Meteorological Observatory (Director, K. Miyoshi).

The record was furnished by an Omori Horizontal Pendulum

of small multiplication,* whose instrumental details were as follows :—

Vertical height between the points of suspension and of support = 75 cm.

Length of the horizontal strut = 12 cm.

Horizontal distance between the writing index and the centre of the heavy bob = 60 cm.

Weight of the heavy bob = $6\frac{1}{2}$ kg.

Multiplication = 6 times.

Oscillation period of the pendulum = 15 sec.

The Observatory is situated on flat ground, about 78 m above the sea-level.

1st Preliminary Tremor. Duration = $6^m 14^s$. The motion was uniform and consisted of the following vibrations :— $T = 4.5$ sec., $2a = 0.17$ mm ; there being at one place some vibrations of $T = 5.8$ sec.

2nd Preliminary Tremor. Duration = $5^m 10^s$. The motion was regular and very nearly uniform :— $T = 4.9$ sec., $2a = 0.33$ mm. In the latter half of this phase, there were also the following vibrations :— $T = 10.2$ sec., $2a = 0.3$ mm.

Principal Portion. [*1st and 2nd phases.*] Duration = $4^m 50^s$. During the first $2^m 9^s$, the motion was comparatively small :— $T = 4.4$ sec., $2a = 0.23$ mm ; $T = 9.3$ sec., $2a = 0.73$ mm. Then there appeared some traces of slow movements, the motion during the next $1^m 49^s$ being as follows :— $T = 6.8$ sec., $2a = 0.5$ mm ; $T = 4.7$ sec., $2a = 0.23$ mm ; $T = 16.5$ sec.

Then there followed three large vibrations of $T = 10$ sec., whose max. $2a$ was 2.0 mm. In the remaining part of this phase, which formed a minimum epoch, there were small vibrations of

* Described in the *Publications*, No. 5.

T = about 4.5 sec. [3rd phase.] Duration = 5^m 40^s. During the first 1^m 44^s, which formed the maximum group, the motion was as follows :— T = 9.0 sec., $2a$ = 12.8 mm ; the maximum motion having occurred 1^m 30^s after the commencement of this phase. In the subsequent part, the motion was much smaller :— T = 8.9 sec., $2a$ = 6.3 mm ; T = 5.0 sec., $2a$ = 0.33 mm ; T = 14.8 sec., $2a$ = 6.3 mm. The vibrations of the last sort were probably due to the proper pendulum oscillations. During the remaining 3^m 5^s of the principal portion, the motion was nearly uniform :— T = 8.4 sec., $2a$ = 1.2 mm ; T = 22.3 sec.

End Portion. For the first 5^m 40^s, the motion was nearly constant :— T = 8.8 sec., $2a$ = 0.5 mm ; T = 5.3 sec. ; T = 4.0 sec. ; there being also some traces of slow vibrations. The subsequent motion became again smaller :—

$$T = 8.9 \text{ sec.}, \quad 2a = 0.2 \text{ mm} ;$$

$$T = 6.4 \text{ „ „}, \quad 2a = 0.17 \text{ „ „} ;$$

$$T = 13.6 \text{ „ „}, \quad 2a = 0.17 \text{ „ „} .$$

Towards the very end :— T = 10.5 sec.

27. Tainan, Formosa, Japan. *EW Component.* (See Pl. VIII, the *Publications*, No. 23.) The Meteorological Observatory (Director, T. Endo).

The record was furnished by an Omori Horizontal Pendulum of small multiplication, exactly similar to the one in use at Taichu (§ 26), the only difference being that the Tainan instrument had a natural oscillation period of 17 sec. The observatory stands on low ground about 14 m above the sea-level.

1st Preliminary Tremor. Duration = 6^m 15^s. The motion consisted essentially of the following vibrations :— T = 4.0 sec., $2a$ = 0.12 mm. After 1^m 49^s from the commencement, there appeared

2nd Preliminary Tremor; 1st and 2nd Phases of Principal Portion. Total duration = $9^m 46^s$. During the first $6^m 27^s$, the motion was smaller:— $T = 12.1$ sec., $2a = 2.3$ mm; there being at minimum epochs also some small vibrations. The 2nd preliminary tremor, which was markedly larger than the 1st preliminary tremor, began with a vibration whose two displacements were as follows:—

During the remaining part, the motion became gradually larger :— $T=11.8$ sec., $2a=4.6$ mm ; $T=15.3$ sec. (pendulum oscillations ?)

28. O'Gyalla, (near Budapest), Austria-Hungary. Royal Meteorological and Geodynamic Observatory. (Director, N. Thege v. Konkoly jr.; Assistant, A. Réthly.)

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(NS) In the 2nd preliminary tremor, the motion was as follows :— $T=8.4$ sec., $2a=0.4$ mm ; $T=17.2$ sec., $2a=1.4$ mm (pend. oscillations). The max. $2a=2.7$ mm ($T=19.8$ sec.) occurred $22^m 50^s$ after the commencement of the earthquake, the motion remaining active for the next 10 m.

29. Birmingham, England. *EW Component.* (See Pl. X, the *Publications*, No. 23.)

The observation was made by Dr. C. Davison* with an Omori Horizontal Pendulum, whose instrumental constants were as follows :—

Vertical distance between the point of suspension
and the point of support = 0.85 metre.

Horizontal distance between the point of support
and the centre of the heavy bob = 0.70 metre.

Weight of the mass = 9 kg.

Multiplication-ratio of the writing-index = 14.4.

Oscillation period of the pendulum = 34 sec.

Velocity of recording paper = 10.8 mm per sec.

Time of commencement = $1^h 0^m 35^s$. Total Duration = $2^h 40^m$.

1st Preliminary Tremor. Duration = $8^m 21^s$:— $T=12.0$ sec., $2a=0.035$ mm ; $T=4.6$ sec. ; $T=7.1$ sec.

2nd Preliminary Tremor began at $1^h 8^m 56^s$. Duration = $7^m 37^s$:— $T=15.5$ sec., $2a=0.083$ mm ; $T=4.6$ sec., $T=9.7$ sec., $2a=0.028$ mm.

Principal Portion began at $1^h 16^m 33^s$. [*1st and 2nd phases.*] Duration = $8^m 49^s$. During the first $6^m 39^s$, the motion was small :— $T=9.9$ sec., $2a=0.07$ mm ; $T=18.8$ sec., $2a=0.16$ mm. During the remaining $2^m 10^s$, the motion became larger and consisted of $3\frac{1}{2}$ nearly equal vibrations :— $T=36.6$ sec., $2a=0.24$ mm ; $T=7.5$

* An account of the seismogram is given by Dr. Davison in the *Boll. d. Soc. Sism. Italiana*, Vol. X.

sec. [*3rd phase.*] Commencement = $1^h 25^m 22^s$. Duration = $9^m 30^s$. During the first $2^m 37^s$, there was a gradually increasing series of 5 vibrations, due to the proper pendulum motion :— $T=31.4$ sec., $2a=2.03$ mm, the greatest being the 4th vibration. For the next $4^m 3^s$, the motion was small :— $T=18.7$ sec., $2a=0.73$ mm. For the remaining $2^m 51^s$, the motion was larger and regular :— $T=17.1$ sec., $2a=1.56$ mm. [*4th phase.*] Commencement = $1^h 34^m 52^s$. Duration = $6^m 21^s$. The motion was small :— $T=12.3$ sec., $2a=0.60$ mm.

For the next $10^m 30^s$, the motion remained nearly constant :— $T=14.7$ sec., $2a=0.25$ mm ; $T=9.7$ sec., $2a=0.042$ mm. The subsequent motion gradually diminished, the vibrations for the next 8^m being as follows :— $T=14.3$ sec., $2a=0.13$ mm ; $T=10.4$ sec. The average period, deduced from 3 successive series, each of 30 vibrations, was as follows :—

$$\left. \begin{array}{l} 16.1 \text{ sec.} \\ 16.1 \\ 17.9 \end{array} \right\} \dots \text{mean, } 16.7 \text{ sec.}$$

30. Washington, D.C., U.S.A. *NS Component.* (See Pl. IX, the *Publications*, No. 23.) U.S. Weather Bureau. (Professor C. F. Marvin.)

The record was furnished by the Weather Bureau (Omori type) Seismograph, whose instrumental constants were as follows :—

Multiplication = 10.

Oscillation period of pendulum = about 19 sec.

Time of commencement = $1^h 8^m 25^s$. Total Duration = $2^h 30^m$.

1st Preliminary Tremor. Duration = $15^m 2^s$. During the first $6^m 24^s$, the motion was very small and doubtful. During the remaining $8^m 38^s$ the period was as follows :— $T=43$ sec. (?) ; $T=6.3$ sec.

2nd Preliminary Tremor began at $1^h 23^m 27^s$. Duration = $12^m 9^s$. The motion was small :— $T=21.4$ sec. ; 28 sec. ; 39.5 sec.

Principal Portion began at $1^h 35^m 36^s$. [*1st and 2nd phases.*] Duration = $15^m 41^s$. The movements during the successive epochs were as follows.

- (i) $5^m 10^s$:—Motion small and irregular :— $T=44.3$ sec. (?)
- (ii) $3^m 18^s$:—Motion well defined :— $T=49.5$ sec., $2a=0.05$ mm.
- (iii) $7^m 13^s$:— $T=27.8$ sec., $2a=0.08$ mm.

[*3rd phase.*] Commencement = $1^h 51^m 17^s$. Duration = $22^m 50^s$. During the first $2^m 16^s$, the motion was regular :— $T=19.4$ sec. (pend. oscillations), the max. $2a=1.2$ mm occurring at $1^h 52^m 39^s$. During the next $20^m 34^s$, the motion was much smaller and quicker :— $T=15.1$ sec. The subsequent motion was small.

W_2 began to appear at $2^h 27^m 28^s$, when the motion became distinctly larger, for about 10^m :— $T=16.5$ sec. Thereafter the motion was small, till about $2^h 52^m 30^s$, when there appeared again distinct slow vibrations, for $5^m 50^s$:— $T=27$ sec. At $2^h 58^m 43^s$, the motion became more distinct :— $T=21.9$ sec. ; 13.5 sec. These movements lasted till $3^h 12^m 0^s$, the subsequent motion gradually decreasing.

31. *Cheltenham*, Maryland, U.S.A.

Magnetic Observatory of the U.S. Coast and Geodetic Survey.
(Superintendent, Dr. O. H. Tittman ; Observer, J. E. Burbank.)

The motion was recorded by a pair of Omori Horizontal Pendulums, whose magnification was 10, the oscillation periods of the pendulums being as follows :—

$$\left\{ \begin{array}{l} \text{EW Component} \dots\dots\dots 21 \text{ sec.} \\ \text{NS} \quad \quad \quad \dots\dots\dots 19 \text{ ,,} \end{array} \right.$$

Time of earthquake occurrence = $1^h 8^m 39^s$. Total duration = $3^h 45^m$.

(I) *EW Component.* (Pl. IX, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration = $14^m 42^s$. For the first $6^m 18^s$, the motion was very small and doubtful. For the next $8^m 24^s$, the motion became slightly but distinctly larger, vibrations being greater at the commencement :— $T=12.3$ sec., $2a=0.05$ mm ; $T=7.8$ sec.

2nd Preliminary Tremor commenced at $1^h 23^m 21^s$. Duration = $12^m 14^s$. For the first 2 min. there were 3 slow vibrations :— $T=41$ sec., $2a=0.1$ mm. The subsequent motion consisted essentially of small regular vibrations :— $T=14.4$ sec., $2a=0.05$ mm.

Principal Portion began at $1^h 35^m 35^s$. [*1st and 2nd phases.*] Duration = $13^m 47^s$. The movements during the successive epochs were as follows :—

(i) $3^m 53^s$ The motion was made up of 4 very slow vibrations :—

- | | | | |
|---|-----|--------------------------|------------------------------|
| { | (a) | $1^st 2^m 8^s$ | Two vibrations, $T=64$ sec. |
| | (b) | next $1 48$ | „ „ = 54 „ , $2a=0.12$ mm. |

There were also some very slight vibrations of T = about 15.7 sec.

(ii) $3^m 02^s$ Motion irregular, $2a$ being nearly the same as before :
 $T=45.5$ sec. ; 22.4 sec.

(iii) $6^m 42^s$ Motion smaller :— $T=30.0$ sec., $2a=0.08$ mm ; $T=14.7$ sec.

[*3rd phase.*] Commencement = $1^h 49^m 12^s$. Duration = $11^m 0^s$. During the first $1^m 56^s$ the motion was small. The two max. $2a$'s of 0.83 mm (absolute maximum) and 0.60 mm occurred respectively at $1^h 52^m 54^s$ and $1^h 58^m 38^s$:— $T=19.7$ sec.

The subsequent motion was as follows :—

(i) 23^m 25^s Motion nearly constant :— $T=15.2$ sec., $2a=0.2$ mm ; $T=19.9$ sec., $2a=0.36$ mm.

(ii) 29^m 12^s Motion very regular :— $T=16.0$ sec., $2a=0.21$ mm.

The vibrations occurred in groups whose mean interval was 3.0 minutes.

(iii) 5^m 20^s Motion small :— $T=19.4$ sec.

(iv) 4^m 5^s Motion slightly larger, and nearly uniform :— $T=21.3$ sec., $2a=0.1$ mm.

The subsequent motion belonged to W_2 .

W_2 . The motion in the successive epochs was as follows :—

(i) 4^m 36^s Motion regular, forming a conspicuous maximum group :— $T=19.7$ sec., $2a=0.28$ mm.

The maximum motion occurred at about 2^h 4^m 18^s.

(ii) 2^m 5^s Motion small.

(iii) 4 20 There was a 2nd maximum group :— $T=17.4$ sec., $2a=0.11$ mm.

Thereafter the motion gradually diminished, with alternations of max. and min. groups.

The record, as described above, consists almost entirely of the pendulum oscillations, whose mean period comes out to be 20.4 sec.

(II) *NS Component.* (Pl. IX, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration = 14^m 45^s. the movements during the successive epochs were as follows :—

(i) 6^m 0^s Motion very small :— $T=7.1$ sec.

(ii) 3^m 32^s $T=30.3$ sec. (?)

(iii) 2^m 2^s There were 3 vibrations :— $T=40.7$ sec., $2a=0.15$ mm.

(iv) 3^m 11^s Motion small : $T=12.6$ sec.

2nd Preliminary Tremor began at 1^h 23^m 23^s. The duration was 12^m 16^s.

- (i) 1^m 32^s 3 slow vibrations :— $T=30.7$ sec., $2a=0.09$ mm ; $T=8.4$ sec., $2a=\text{small}$.
- (ii) 3^m 41^s Motion small :— $T=11.2$ sec.
- (iii) 3^m 4^s 3 slow vibrations :— $T=46.0$ sec., $2a=0.07$ mm.
- (iv) 3^m 58^s Motion small :— $T=24.6$ sec., $2a=0.06$ mm.

Principal Portion began at 1^h 35^m 39^s. [*1st and 2nd phases.*]
Duration=15^m 31^s. The motion during the successive epochs was as follows :—

- (i) 6^m 25^s Motion consisted of small irregular vibrations :— $T=62.3$ sec., $2a=0.14$ mm ; $T=25.8$ sec.
- (ii) 2^m 0^s $T=48.0$ sec., $2a=0.09$ mm ; $T=14.1$ sec.
- (iii) 7^m 6^s $T=29.8$ sec., $2a=0.24$ mm.

[*3rd phase.*] Commencement=1^h 51^m 10^s : Duration=11^m 52^s.
Successive movements were as follows :—

- (i) 2^m 58^s Motion was most active :— $T=18.6$ sec., $2a=2.12$ mm.

The maximum vibration (pendulum oscillation) was the 4th one, and occurred at 1^h 52^m 15^s.

- (ii) 4^m 3^s Motion small :— $T=21.2$ sec.
- (iii) 4^m 54^s Motion again larger, and uniform :— $T=16.3$ sec., $2a=0.57$ mm (pendulum oscillations.)

[*4th phase.*] commencement=2^h 3^m 2^s; duration=11^m 20^s. The motion consisted entirely of the pendulum oscillations :— $T=16.4$ sec., $2a=0.21$ mm.

[*5th phase and end portion.*] Commencement=2^h 14^m 22^s. Successive movements were as follows :—

- (i) 5^m 19^s Motion small.
- (ii) 14^m 2^s Motion again larger, and nearly uniform :— $2a=0.12$ mm (pendulum oscillations).
- (iii) 17^m 51^s Motion small :— $T=21.6$ sec., $2a=0.05$ mm ; $T=15.8$ sec., $2a=0.1$ mm.

The subsequent motion belongs to W_2 .

W_2 appeared at 2^h 51^m 27^s. Successive movements were as follows :—

- (i) 5^m 19^s Motion consisted of small slow vibrations :— $T=29.0$ sec., $2a=0.06$ mm.
- (ii) 1^m 46^s Motion small :— $T=23.6$ sec., $2a=0.06$ mm.
- (iii) 4^m 46^s Motion larger and regular :— $T=22.0$ sec., $2a=0.19$ mm.
- (iv) 10^m 10^s Motion smaller :— $T=18.5$ sec., $2a=0.06$ mm.

Thereafter the motion gradually diminished, with some alternations of max. and min. groups.

W_3 occurred at 5^h 22^m 4^s.

The period of the free pendulum oscillation comes out, on the average, to be 18.2 sec.

32. Tacubaya, Mexico.

Observatorio Astronomico Nacional Mexicano. (Director, Ing. F. Valle.)

The registers were furnished by a pair of Omori Horizontal Pendulums, whose magnification was 10, the oscillation periods of the pendulums being as follows :—

$$\begin{cases} \text{EW Component} & \dots\dots\dots 17.3 \text{ sec.} \\ \text{NS} & \text{,,} \dots\dots\dots 17.6 \text{ ,,} \end{cases}$$

Time of commencement = 1^h 11^m 25^s.

(i) **EW Component.** (Pl. X. the *Publications*, No. 23.)

Total duration = 2^h 40^m.

1st Preliminary Tremor. Duration = 16^m 38^s, the beginning being marked by small but distinct vibrations. Motion was nearly uniform :— $T=7.7$ sec., ; $T=14.2$.

2nd Preliminary Tremor began at $1^h 28^m 3^s$. Duration = $15^m 42^s$. Successive movements were as follows :—

- (i) $6^m 30^s$ Motion distinct :— $T=32.2$ sec., $2a=0.10$ mm.; the maximum motion occurring at the commencement and end of this epoch.
- (ii) $9^m 12^s$ Motion much smaller :— $T=11.7$ sec.

Principal Portion began at $1^h 43^m 45^s$. [*1st and 2nd phases.*] Duration = $18^m 4^s$. This phase is characterized by the appearance of well defined slow vibrations, the motion in the successive epochs being as follows :—

- (i) $6^m 42^s$ Motion regular :— $T=57.4$ sec., $2a=0.1$ mm.
- (ii) $3^m 3^s$ Motion regular :— $T=45.8$ sec., $2a=0.1$ mm.
- (iii) $5^m 0^s$ Motion larger and quicker :— $T=37.5$ sec., $2a=0.12$ mm.
- (iv) $3^m 19^s$ Motion very small :— $T=24.8$ sec.

[*3rd phase.*] Commencement = $2^h 1^m 49^s$. Duration = $14^m 52^s$. Motion was well defined. For the first $10^m 30^s$:— $T=22.5$ sec., $2a=0.12$ mm. For the next $4^m 22^s$:— $T=18.1$ sec., $2a=0.15$ mm.

[*4th phase, etc.*] Commencement = $2^h 16^m 41^s$. During the first $27^m 5^s$, the motion very gradually diminished :— $T=15.9$ sec.; 17.8 sec.; 17.1 sec.; 18.0 sec.; 21.2 sec.

Then followed the W_2 motion.

W_2 began at $2^h 43^m 46^s$. For the first $20^m 35^s$, the motion was well defined :— $T=18.0$ sec., $2a=0.1$ mm. Thereafter the motion became gradually small. The period of the proper pendulum oscillations, given above, are included between 15.9 and 18.1 sec., giving the average value of 17.5 sec.

(ii) **NS Component.** (Pl. X, the *Publications*, No. 23.)

Total duration = 3 hours.

The 1st and 2nd preliminary tremors, 1st and 2nd phases of the principal portion were not well defined.

In the 1st preliminary tremor :— $T=8.9$ sec.

At 42^m 45^s after the commencement of the earthquake, there appeared slow vibrations, the movements in the successive epochs being as follows :—

(i) 2^m 15^s $T=45.0$ sec., $2a=0.1$ mm.

(ii) 2 41 „ $=40.3$ „ „ „ $=0.1$ „ .

Then the motion became small :—

(iii) 10^m 15^s $T=24.5$ sec.

(iv) 1 57 Motion larger :— $T=23.4$ sec., $2a=0.12$ mm.

(v) 6 51 Motion quicker and most active :— $T=15.8$ sec., $2a=0.30$ mm (pend. osc.); the vibrations being specially large and uniform during the last 2^m 16^s.

Then the motion gradually diminished :—

(vi) 5^m 25^s $T=16.3$ sec.

W_2 occurred 1^h 37^m after the commencement of the earthquake, or at 2^h 48^m 25^s, and the motion was, for the first 5^m, remarkably large and regular :— $T=19.4$ sec., $2a=0.48$ mm (pendulum oscillations.); this being much greater than W_1 or the earthquake proper. For the next 15^m 30^s, the motion was smaller, but still active :— $T=16.0$ sec., $2a=0.15$ mm (pendulum oscillations).

The successive max. groups occurred at an average interval of 3^m 30^s.

33. Quarto Castello, Florence, Italy. (Pl. XI, the *Publications*, No. 23.) Osservatorio Geodinamico (R. Stiattesi).

The earthquake was recorded by the Grande Pendolo Orizzontale (Stiattesi) and the Grande Microsismografo “Vicentini” a pantografo. The constants of these instruments were as follows.

Grande Pend. Oriz. (Stiattesi) :—

EW Component	{	Weight of the bob = 500 kg.
		Magnification = 50
		Proper period = 17.4 sec.
NS Component	{	Weight of the bob = 500 kg.
		Magnification = 50
		Proper period = 21.4 sec.
"Vicentini" a pantografo	{	Weight of the bob = 500 kg.
		Magnification = 80
		Proper period = 4.6 sec.

The duration of the 1st preliminary tremor was as follows :—

Pend. Oriz., EW	7 ^m 20 ^s	{	<i>mean</i> , 7 ^m 17 ^s .
„ NS	7 9		
Vicentini	7 22		

The commencement of motion was somewhat obscure. If we take the first well-defined vibration, the time interval between the latter and the end of the 1st preliminary tremor was as follows :—Pend. Oriz. EW, 7^m 0^s; Pend. Oriz. NS, 7^m 0^s; Vicentini, 7^m 18^s.

(i) Pendolo Orizzontale. **EW Component.**

Time of commencement = 0^h 58^m 49^s. Total duration = 2^h 47^m.

1st Preliminary Tremor. Duration = 7^m 20^s. During the first 20 sec., the motion was very small. This was followed by a vibration of $2a = 0.056$ mm, $T = 7.4$ sec, the motion remaining active for the next 69 sec. The subsequent vibrations were as follows :— $T = 4.3$ sec., $2a = 0.04$ mm; $T = 9.1$ sec., $2a = 0.07$. The motion during the last 2^m 21^s of this portion was very small.

2nd Preliminary Tremor; 1st and 2nd Phases of Principal Portion. Commencement = 1^h 06^m 7^s. Duration = 14^m 40^s. The successive movements were as follows.

- (i) 4^m 28^s The motion was active :— $T=9.7$ sec., $2a=0.26$ mm
 $T=3.1$ sec. (?).
- (ii) 3^m 17^s Motion small :— $T=4.9$ sec., $2a=0.04$ mm ;
 $T=8.2$ sec., $2a=0.10$ mm.
- (iii) 6^m 55^s :— $T=9.2$ sec., $2a=0.12$ mm ; $T=4.9$ sec.

3rd Phase of Principal Portion, etc. The successive movements were as follows :—

- (i) 4^m 50^s :— $T=11.5$ sec., $2a=0.22$ mm ; $T=11.5$ sec., $2a=0.22$ mm ;
 $T=14.7$ sec., $2a=0.44$ mm ; $T=7.1$ sec., $2a=0.034$ mm.
- (ii) 6^m 0^s The motion was most active, this part corresponding to the epoch in the NS component, in which the motion was small and which followed the largest pendulum oscillations :—
 $T=18.1$ sec., $2a=1.2$ mm. (pend. osc.) ; $T=10.2$ sec., $2a=0.44$ mm.
- (iii) 6^m 32^s Motion smaller :—
- $$\left\{ \begin{array}{l} T=18.6 \text{ sec., } 2a=0.34 \text{ mm (pend. osc.)} \\ ,,=14.6 \text{ ,, , } ,,=0.57 \text{ ,,} \\ ,,=10.3 \text{ ,, , } ,,=0.38 \text{ ,,} \\ ,,=4.8 \text{ ,, , } ,, \text{ small.} \end{array} \right.$$
- (iv) 9^m 20^s Motion regular :— $T=14.1$ sec., $2a=0.14$ mm ; $T=7.9$ sec.
- (v) 12^m 2^s Motion very small :— $T=16.5$ sec., $2a=0.09$ mm (pend. osc.)
- (vi) 11^m 15^s Motion very small.
- (The further continuation is not given in the copy.)

(ii) Pendolo Orizzontale. **NS Component.**

1st Preliminary Tremor. Duration = 7^m 9^s. For the first 14 sec., the motion was small and partly obscure. Then there took place the following vibration :— $T=7.0$ sec., $2a=0.08$ mm. The subsequent motion was small and nearly constant :— $T=4.3$ sec. ; $T=6.4$ sec.

2nd Preliminary Tremor ; 1st and 2nd Phases of the Principal Portion. Commencement = $1^h 05^m 56^s$. Duration = $15^m 09^s$. The first $7^m 22^s$ probably corresponds to the *2nd preliminary tremor*, the vibrations being as follows :—

$$\left\{ \begin{array}{l} T=11.1 \text{ sec., } 2a=0.25 \text{ mm. ;} \\ \text{,,} = 4.7 \text{ ,, , ,,} = 0.02 \text{ ,, ;} \\ \text{,,} = 8.2 \text{ ,, , ,,} = 0.14 \text{ ,, ;} \\ \text{,,} = 54.5 \text{ ,, , ,,} = 0.51 \text{ ,, .} \end{array} \right.$$

the maximum vibration of the last set occurring at the commencement of this phase.

The next $4^m 22^s$ probably corresponds to the *1st phase of principal portion*. The motion was small :— $T=9.6$ sec., $2a=0.058$ mm ; $T=50.0$ sec., $2a=0.22$.

The remaining $3^m 21^s$ corresponds to the *2nd phase of the principal portion*, the motion becoming more active :— $T=8.3$ sec., $2a=0.30$ mm ; $T=29.8$ sec., $2a=0.44$.

3rd Phase of Principal Portion began at $1^h 21^m 05^s$. Duration = $8^m 15^s$. The successive movements were as follows :—

- (i) $0^m 53^s$. . . Motion small ;— $T=15.2$ sec., $2a=0.63$ mm ; the maximum vibration occurring at the beginning.
- (ii) $2^m 51^s$. . . The motion consisted of 8 large pendulum oscillations :— $T=21.4$ sec., $2a=4.9$ mm.
- (iii) $2^m 29^s$. . . The motion became abruptly small :— $T=26.6$ sec., $2a=0.72$ mm ; $T=9.5$ sec., $2a=0.16$ mm.
- (iv) $1^m 58^s$. . . Motion again larger :— $T=20.7$ sec., $2a=2.06$ mm (pend. osc.) ; $T=8.5$ sec., $2a=0.14$ mm.

The motion during the subsequent phases was as follows.

- (i) $15^m 42^s$. . . The motion was on the whole constant :—

$$\left\{ \begin{array}{l} T=12.2 \text{ sec., } 2a=0.46 \text{ mm. ;} \\ \text{,,} = 14.6 \text{ ,, (?) , ,,} = 0.20 \text{ ,, ;} \\ \text{,,} = 18.8 \text{ ,, , ,,} = 0.48 \text{ ,, .} \end{array} \right.$$

(ii) 15^m 23^s.... The motion much smaller:—

$$\left\{ \begin{array}{l} T=16.8 \text{ sec., } 2a=0.22 \text{ mm.}; \\ \text{,,}=11.9 \text{ ,, , , }=0.15 \text{ ,, }; \\ \text{,,}=4.9 \text{ ,, , small.} \end{array} \right.$$

Thereafter the motion became much smaller.

(iii) *Comparison of the EW and NS Components.* The following table gives a comparison of the periods and amplitudes occurring in the two horizontal components.

Quarto Castello. EW and NS components compared.

EW Component.	NS Component.	2 Components taken together.
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1st Preliminary Tremor.

Duration=7^m 20^s.....7^m 9^s.

$\left\{ \begin{array}{ll} T=4.3 \text{ sec., } 2a=0.04 \text{ mm} \\ \text{—} & \text{—} \\ 9.1 & 0.07 \end{array} \right.$	$\left\{ \begin{array}{ll} T=4.3 \text{ sec., } 2a=0.02 \text{ mm} \\ 6.4 & 0.02 \\ \text{—} & \text{—} \end{array} \right.$	$\left\{ \begin{array}{ll} T=\mathbf{4.3} \text{ sec., } 2a=0.04 \text{ mm} \\ 6.4 & 0.02 \\ 9.1 & 0.07 \end{array} \right.$
--	--	--

2nd Preliminary Tremor.

Duration=7^m 45^s.....7^m 22^s.

$\left\{ \begin{array}{ll} T=4.9 \text{ sec., } 2a=0.04 \text{ mm} \\ 9.0 & 0.26 \\ \text{—} & \text{—} \\ \text{—} & \text{—} \end{array} \right.$	$\left\{ \begin{array}{ll} T=4.7 \text{ sec., } 2a=0.02 \text{ mm} \\ 8.2 & 0.14 \\ 11.1 & 0.25 \\ 54.5 & 0.51 \end{array} \right.$	$\left\{ \begin{array}{ll} T=\mathbf{4.8} \text{ sec., } 2a=0.04 \text{ mm} \\ \mathbf{8.6} & 0.26 \\ 11.1 & 0.25 \\ 54.5 & 0.51 \end{array} \right.$
---	---	---

1st and 2nd Phases, Principal Portion.

Duration=6^m 55^s.....7^m 43^s.

$\left\{ \begin{array}{ll} T=4.9 \text{ sec., } 2a=\text{small.} \\ 9.2 & 0.12 \text{ mm} \\ \text{—} & \text{—} \\ \text{—} & \text{—} \end{array} \right.$	$\left\{ \begin{array}{ll} T=\text{—} & 2a=\text{—} \\ 9.0 \text{ sec., } 0.30 \text{ mm} & \\ 29.8 & 0.44 \\ 50.0 & 0.22 \end{array} \right.$	$\left\{ \begin{array}{ll} T=4.9 \text{ sec., } 2a=\text{—} \text{ mm} \\ \mathbf{9.1} & 0.30 \\ 29.8 & 0.44 \\ 50.0 & 0.22 \end{array} \right.$
--	--	--

EW Component.	NS Component.	2 Components taken together.
3rd Phase, Principal Portion.		
Duration = 10 ^m 50 ^s 8 ^m 15 ^s .		
$\left\{ \begin{array}{ll} T=6.9 \text{ sec., } 2a=0.031 \text{ mm} \\ 10.9 \text{ , } 0.41 \\ 14.7 \text{ , } 0.44 \\ 18.1^* \text{ , } 1.18 \\ \text{—} \text{ , } \text{—} \end{array} \right.$	$\left\{ \begin{array}{ll} T=\text{—} \quad 2a=\text{—} \\ 9.0 \text{ sec., } 0.16 \text{ mm} \\ 15.2 \text{ , } 0.63 \\ 21.1^* \text{ , } 4.9 \\ 26.6 \text{ , } 0.72 \end{array} \right.$	$\left\{ \begin{array}{ll} T=6.9 \text{ sec. } 2a=0.031 \text{ mm} \\ \mathbf{10.0} \quad 0.44 \\ \mathbf{15.0} \quad 0.63 \\ \text{—} \quad 4.9 \\ 26.6 \quad 0.72 \end{array} \right.$
4th, etc. Phases, and End Portion.		
$\left\{ \begin{array}{ll} T=1.8 \text{ sec., } 2a=\text{small.} \\ \text{—} \quad \text{—} \\ 9.1 \text{ , } 0.38 \\ 14.4 \text{ , } 0.57 \\ 16.5 \text{ , } 0.09 \\ 18.6 \text{ , } 0.31 \end{array} \right.$	$\left\{ \begin{array}{ll} T=4.9 \text{ sec., } 2a=\text{small.} \\ \text{—} \quad \text{—} \\ 12.1 \quad 0.46 \text{ mm} \\ 14.6 \quad 0.20 \\ 16.8 \quad 0.22 \\ 18.8 \quad 0.48 \end{array} \right.$	$\left\{ \begin{array}{ll} T=\mathbf{4.9} \text{ sec. } 2a=\text{—} \text{ mm} \\ 9.1 \quad 0.38 \\ 12.1 \quad 0.46 \\ \mathbf{14.5} \quad 0.57 \\ \mathbf{16.7} \quad 0.22 \\ \mathbf{18.8} \quad 0.48 \end{array} \right.$

* Pendulum motion.

34. Querce, Florence, Italy.

Osservatorio Geodinamico del Collegio “ alla Querce.” (Director, Padre Camillo Melzi d’Eril.)

The following is an analysis made on a lithographic reproduction of the records from two Stiattesi Horizontal Pendulums, which registered in the directions NW-SE and NE-SW, and whose magnification was 25; the diagram consisting almost entirely of the pendulum oscillations.

NW-SE Component.	NE-SW Component.
<i>1st Preliminary Tremor.</i>	
Duration = 7 ^m 15 ^s	 7 ^m 16 ^s
$T=3.7 \text{ sec.}$	 3.6 sec.
$\left\{ \begin{array}{l} \text{„}=8.7 \text{ „} \\ 2a=0.08 \text{ mm} \end{array} \right.$	$\left\{ \begin{array}{l} 7.8 \text{ „} \\ 0.072 \text{ mm} \end{array} \right.$
The motion became larger 3 ^m 26 ^s after the commencement.	

2nd Preliminary Tremor and Principal Portion.

Large pendulum oscillations appeared at

13^m 45^s

12^m 10^s

after the commencement of the 2nd preliminary tremor, the motion remaining specially large during the next

18^m 58^s ($2a = 6.2$ mm)

24^m 48^s ($2a = 2.2$ mm)

Pendulum period = 17.6 sec. 15.5 sec.

The absolutely greatest group in the (NW—SE) component occurred between 1^h 7^m 55^s and 1^h 8^m 46^s.

Then the motion became smaller, but the pendulum oscillations remained still active for the next

22^m 0^s ($2a = 2.2$ mm)

13^m 18^s ($2a = 1.3$ mm.)

About 3 hours after the commencement of the eqke :—

T (of pend. oscu.) = 17.6 sec. 16.2 sec.

End of motion 4^h 22^m 43^s 4^h 45^m

W₂ : NW—SE Component.

The W₂ motion began at 3^h 10^m 50^s. The vibrations during the successive epochs being as follows.

- (i) 5^m 24^s Motion active :—T = 15.1 sec., $2a = 0.12$ mm.
- (ii) 3^m 46^s Motion small.
- (iii) 8^m 12^s Motion a little larger.
- (iv) 6^m 38^s Motion again active :—T = 18.1 sec., $2a = 0.12$ mm.
- (v) 4^m 16^s Motion small.
- (vi) 4^m 13^s Motion slightly larger.
- (vii) 4^m 31^s Motion active :—T = 18.0 sec., $2a = 0.14$ mm.
- (viii) 4^m 36^s Most active :—T = 18.0 sec., $2a = 0.27$ mm.
- (ix) 4^m 48^s Small.
- (x) 6^m 16^s Very small,

Then there followed a series of small max. groups at an average interval of $4^m 18^s$.

W_2 : *NE—SW Component.*

In this component, the W_2 vibration continued for about $15^m 30^s$, the motion being not so marked as in the other:— $T=21.3$ sec., $2a=0.03$ mm.

Periods of vibration. The real earthquake T 's are those indicated in the 1st preliminary tremor, whose mean values are: $T=3.7$ sec.; $T=8.3$ sec. ($2a=0.08$ mm, NW—SE component.) All the other periods given above are due to the proper pendulum oscillation, being as follows:—

NW—SE Component.

$\left\{ \begin{array}{l} 17.6 \text{ sec.} \\ 17.6 \\ 15.1 \\ 18.1 \\ 18.0 \\ 18.0 \end{array} \right.$

NE—SW Component.

$\left\{ \begin{array}{l} 15.5 \text{ sec.} \\ 16.2 \end{array} \right.$

The mean periods for the two component pendulums thus come out to be 17.4 and 15.9 sec., respectively.

The following tabular statement of the elements of motion is taken from the “*Bollettino dell'Osservatorio Geodinamico del Collegio alla Querce a Firenze.*” No. 4, 1905.

NE-SW Component.			NW-SE Component.		
Times.	T	$2a$	Times.	T	$2a$
$0^h 59^m 08^s$	$3.5^{sec.}$	1.5^{mm}	$0^h 59^m 08^s$	$3.8^{sec.}$	1.5^{mm}
1 06 23	16.1	25.0	1 06 23	9.5	19.0
1 18 54	16.3	38.0	1 21 51	17.7	121.0

NE-SW Component			NW-SE Component.		
Times.	T	$2a$	Times.	T	$2a$
^h ^m ^s 1 25 11	^{sec.} 15.6	^{mm.} 57.0	^h ^m ^s 1 28 19	^{sec.} 17.6	^{mm.} 152.0
1 35 21	16.3	38.0	1 35 42	18.6	95.0
2 04 25	16.4	10.0	2 04 40	19.1	13.0
3 25 21	19.9	1.5	3 28 19	17.2	4.0
3 49 28	34.4	0.3	3 58 25	17.5	0.5
4 22 43. (End)			4 45 00. (End)		

35. Ximentiano, Florence, Italy. Osservatorio Geodinamico, (Padre G. Alfani.)

Commencement = 0^h 58^m 33^s. Total duration = 4^h 12^m.

The following is a note on a lithographic copy of the record from a Tromometrografo Omori, whose instrumental constants were as follows: weight of the bob = 150 kg, period of the free oscillation = 20 sec., velocity of the smoked paper = 100 cm per hour.

1st Preliminary Tremor. The motion was small and uniform:— $T = 3.9$ sec.; $T = 9.6$ sec.

2nd Preliminary Tremor. $T = 8.7$ sec.; $T = 16.8$ sec.

In the principal portion, the record consisted almost entirely of the proper pendulum oscillations, whose T in the two horizontal components were 17.1 and 17.2 sec., respectively.

The following list of the times of occurrence of the different phases of motion, of the periods and amplitudes (*unreduced* ranges of actual tracing), is taken from the *Bolletino Sismologico del l'Osservatorio Ximentiano*, N. 4, 1905. Abbreviations:—

{	Microsismografo Vicentini	:	Pantografo	=	mP
	„	:	Vertical	=	mV
	Pendolo Orizzontale Stiattesi	:	EW	=	EW
	„	:	NS	=	NS
	Tromometrografo Omori	:	NW-SE	=	TN
	„	:	SW-NE	=	TS.

Instru- ments.	I (1st Prel. Trem.)	II (2nd Prel. Trem.)	III (Princ. Portion).			IV (Tail.)	End.
	h m s	h m s	1st ph.	2nd ph.	3rd ph.	h m s	h m s
mP	0.58.44	1.06.12	—	1.16.14	—	1.26.44	2 16.00
mV	0.58.54	1.12.07	—	1.22.00	—	—	—
NS	0.58.32	1.05.42	1.19.42	1.21.00	—	—	—
EW	0.58.35	1.05.47	—	1.22.00	2.03.00	3.02.00	5.10.00
TN	0.58.32	1.05.07	—	1.19.17	1.33.22	2.00.00	4. ?
TS	0.58.32	1.06.32	—	1.19.32	1.33.37	1.44.17	?

Period, in sec.

Amplitude, in mm

Instru- ments.	I (1st Prel. Trem.)	II (2nd Prel. Trem.)	III			IV (Tail.)	I (1st Prel. Trem.)	II (2nd Prel. Trem.)	III			IV (Tail.)
	1st ph.	2nd ph.	3rd ph.	1st ph.	2nd ph.	3rd ph.	1st ph.	2nd ph.	3rd ph.	1st ph.	2nd ph.	3rd ph.
mP	?	irreg.	—	7.7	—	18.0	6.0	4.0	—	1.5	—	2.5
mV	2.5	—	—	12.5	—	—	1.1	0.5	—	0.5	—	—
NS	5.0	21.3	35.0	—	—	—	0.5	18.0	25.5	—	—	—
EW	4.4 20.0	18.0	—	18.3	17.7	17.5	1.0	7.0	—	16.0	100.	24.10
TN	3.0 6.0	20.0	—	17.2	18.0	16.0	—	—	—	—	—	—
TS	3.0 6.0	10.5	—	19.0	20.0	17.0	—	—	—	—	—	—

From the first table we obtain the following mean values:—

Time of commencement of the earthquake = 0^h 58^m 33^s" " 2nd prel. tremor = 1^h 5^m 47^s.

36. Ischia, Italy. (Pl. XII, the *Publications*, No. 23.) R. Osservatorio Geodinamico. (G. Grablovitz).

Pl. XII, the *Publications*, No. 23, gives the records furnished by the Grablovitz Horizontal Pendulums and the "vasca sismica" at

Porto d'Ischia, and those furnished by similar instruments at Grande Sentinella, Casamicciola. The following is a description of the best among those records, namely, the NS and EW components registered by the horizontal pendulums at Porto d'Ischia.

Time of commencement= $0^h 58^m 56^s$.

NS Component. Pendulum period= 13 sec. *1st Preliminary Tremor* lasted $7^m 18^s$, the motion being small.

2nd Preliminary Tremor began with active pendulum oscillations of $T=13.3$ sec., the max. (abs.) $2a$ of 1.8 mm occurring at the commencement. The motion was small between $1^h 11^m$ and $1^h 21^m$, indicating the predominance of some slow movements. It became moderately active between $1^h 25^m$ and $1^h 35^m$, ($2a=1.2$ mm, $T=12.8$ sec.), there being 5 max. groups at an average interval of 2.4 min. For the next 9^m , between $1^h 35^m$ and $1^h 44^m$, the motion was small. Then took place, for about 2.5 min., a max. group of $2a=1.3$ mm, $T=13.6$ sec.,

Thereafter the motion rapidly decreased.

EW Component. Pendulum period= 17 sec.

1st Preliminary Tremor. Motion was small.

2nd Preliminary Tremor, etc. For the first 16 min., the motion was small. Then, at $1^h 22^m$, there took place the max. (abs.) group, $2a=2.8$ mm, $T=16.4$ sec.; the motion continuing active for 14.5 min., till $1^h 37^m$. Then it became abruptly small, till at $1^h 47^m$ there took place a max. group of $2a=1.3$ mm. After $1^h 49^m$, the motion was very small.

37. *Laibach*, Austria-Hungary.

Erdbebenwarte. (Professor Albin Belar.)

The following is a note on the two horizontal component records furnished by Grablowitz-Belar Horizontal Pendulum.

Time of commencement = $0^h 58^m 51^s$.

1st Preliminary Tremor. Duration = $7^m 17^s$. Motion very small :— $T = 9.3$ sec.

For the next $11^m 45^s$, the motion was well defined at first, but again gradually decreased :— $T = 9.2$ sec. Then took place the max. group, the motion being active for the next $21^m 30^s$:— $T = 9.2$ sec.; max. recorded motion, in each component = 16.4 mm (unreduced). Thereafter the motion became much smaller.

Record from Vicentini Seismograph of magnification = 100.

Time of commencement :—

(EW)	$1^h 58^m 48^s$	} <i>Mean</i>	$1^h 58^m 46^s$.
(NS)	$1 \ 58 \ 44$		

Duration of 1st preliminary tremor :—

(EW)	$7^m \ 3^s$	} <i>Mean</i>	$7^m \ 7^s$.
(NS)	$7 \ 9$		

38. *Pola*, Austria-Hungary.

K. k. Hydrographisches Amt, Abtheilung Geophysik. (W. Kesslitz.)

The record was furnished by a Microsismografo "*Vicentini*" *a tre componenti*, of magnification = 91.

The following description of the seismograph is taken from a note kindly communicated to me by the Geophysical Department of the I. R. Hydrographical Office.

Vertical component : No indication.

NS component :—

$0^h 58^m 43^s$. Commencement.

$1^h \ 6^m \ 0^s$ Commencement of regular oscillations, which lasted till $1^h 10^m 30^s$. At first, $T = 10^s$.

1^h 20^m 36^s. Regular oscillations appeared again, in a series of short max. groups.

1^h 23^m 6^s to 1^h 32^m 12^s.—A continuous series of regular oscillations.

The max. $2a$ of 0.01 mm was observed at 1^h 21^m 0^s, 1^h 25^m 36^s, and 1^h 29^m 12^s. The period during the principal part was 12—13 sec.

End of motion. 1^h 34^m 1^s.

EW component :—

0^h 58^m 44^s. Commencement of irregular (pendulum) vibrations, which, with varying intensity, continued till 1^h 1^m 14^s.

1^h 0^m 8^s. $2a=0.012$ mm, the motion then decreasing.

1^h 5^m 55^s. Beginning of regular vibrations, with occasional breaks.

1^h 18^m 58^s. Commencement of a continuous series of vibrations, composed of two systems of wave motion: the $2a=0.009$ mm of regular oscillations took place at 1^h 27^m 10^s.

At first $T'=10$ sec., later on $T'=12$ sec. From 1^h 32^m 58^s to 1^h 50^m, there were only isolated wave groups.

From the above description, we see that the duration of the *1st preliminary tremor* was as follows :

$$\left. \begin{array}{l} (\text{EW}) \dots\dots 7^{\text{m}} 11^{\text{s}} \\ (\text{NS}) \dots\dots 7 \quad 18 \end{array} \right\} \text{Mean} \dots\dots 7^{\text{m}} 15^{\text{s}}.$$

39. *Triest*, Austria-Hungary.

I.R. Marine Observatory. (Professor E. Mazelle).

The earthquake was recorded by a Vicentini microseismograph and also by a Rebeur-Ehlert horizontal pendulum.

Vicentini Microseismograph. The following analysis is taken from an original note kindly communicated to me by Professor Mazelle,

Time and amplitude.	Vertical	NS Component.	EW Component.
Beginning of 1st phase.	0 ^h 58 ^m 55.7	0 ^h 58 ^m 43.1	0 ^h 58 ^m 44.9
Maximum.	0 59 25.7	0 59 49.1	1 01 8.9
Amplitude*	0.6 mm	0.7 mm	0.8 mm
Beginning of long regular vibrations	1 ^h 6 ^m 5.3	1 ^h 5 ^m 43.1	obscure.
Max. amplitude.*	0.3 mm	1.0 mm	0.5 mm
End	2 ^h 20 ^m	2 ^h 31 ^m	2 ^h 05 ^m

(* The amplitude is given in actual size of the record, not divided by the multiplication ratio.)

The duration of the 1st preliminary tremor was :—

Vertical. 7^m 10^s; NS Comp. 7^m 0^s

Rebeur-Ehlert Horizontal Pendulum. The record was taken photographically, there being three horizontal components as follows :—

(A) In the direction EW; (B) W60°N; (C) W60°S.

Time of occurrence = 0^h 58^m 56^s. Total duration = 3^h 3^m (*Pendulum A*).

The preliminary tremor was not clearly indicated. Its duration was about 6^m 14^s (*Pendulum A*). The first active group of motion lasted as follows :—(A) record too faint; (B) 61^m (in the last 29.2^m, motion smaller and uniform); (C) 59.2^m (especially large for the first 38^m).

Then the motion became much smaller, and nearly uniform :—(A) Record too faint; (B) for 24.3^m; (C) for 24.0^m. Then the motion became again smaller and nearly constant :—(B) for 21.8^m; (C) for 20.3^m. Thereafter the motion was very small.

What seems to correspond to the W_2 motion occurred in the (A) pendulum register at 3^h 13^m 56^s. Later on there appeared in the 3 components, especially in *Pendulum (A)* register, a small maximum at 3^h 51^m 26^s.

40. Manila, Philippine Islands. (Pl. XIII, the *Publications*, No. 23.) The Philippine Weather Bureau. (Director, P. I. Algué, S. J.; Assistant, M. Saderra Masó.)

The record was furnished by a Vicentini Microseismograph, of the following specifications:—

Length of the pendulum=1.5 metres.

Weight of the bob=100 kg.

Period of free oscillation=2.4 sec.

Time of commencement= $0^h 58^m 25^s$. Total duration, more than 2 hours.

The two horizontal components were set up in the directions WSW-ENE and NWN-SES.

WSW-ENE Component.

NWN-SES Component.

1st Preliminary Tremor.

Duration	$6^m 46^s$	$6^m 30^s$
Motion small for the first	17^s	9^s

For the next 4 min. the record consists entirely of pend. oscillations of $T=2.55$ sec.:—

*Max. $2a$	19.5 mm.	18.0 mm.
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During the last $2^m 27^s$ of this portion, the motion was small.

2nd Preliminary Tremor.

Duration	?	$5^m 10^s$
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The pendulum oscillation was specially large during

$2^m 22^s$:—	$3^m 1^s$:—
Max. $2a$14.8 mm	31.0 mm
T	2.7 sec.

* These and subsequent values of max. $2a$ in the Manila diagram are the *actual readings*, or those not divided by the multiplication ratio.

1st and 2nd Phases, Principal Portion.

Duration.... — 6^m 10^s

In this portion, the pendulum oscillation greatly diminished :—

Max. 2a.....2.9 mm 2.0 mm

Proper earthquake motion :—

{ T.....14.3 sec. { Max. 2a 4.0 mm	{ ——— { ———
{ T..... 7.8 sec. { Max. 2a 2.0 mm	{ 8.2 sec.....mean, 8.0 sec. { 3.0 mm.

Thereafter the quick pend. oscillations completely disappeared.

3rd, etc. Phases, Principal Portion.

Motion active and nearly constant for the first

18^m 35^s :— { T..... 9.5 sec. { Max. 2a Small { T.....12.7 sec. { Max. 2a 5.4 mm	19^m 32^s :— { 9.3 sec.....mean, 9.4 sec. { Small { 12.8 sec.....mean, 12.8 sec. { 5.0 mm
--	--

The max. motion occurred at about 1^h 20^m 45^s.

During the next 13 m, the motion was much smaller, but nearly constant, as follows :—

Duration....13^m 30^s { T.....11.8 sec. { Max. 2a 1.9 mm	12^m 46^s { 10.7 sec.....mean, 11.3 sec. { 1.8 mm
--	--

Thereafter the motion gradually diminished.

At about 2^h 20^m, there were some very slight motion :—

T.....16.5 sec.	17.8 sec.....mean, 17.2 sec.
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This may correspond to the W_2 motion.

At 3^h there was still some trace of vibrations.

41. Rocca di Papa, Italy. (Pl. XIII, the *Publications*, No. 23.)

R. Osservatorio Geodinamico. (Prof. Agamennone.)

The following analysis of the records obtained at Rocca di Papa from the Microsismometrografo and Pendolo Orizzontale has been made on a lithographic reproduction, published by Professor Agamennone.

(1) Microsismometrografo "Agamennone" :—

$$\left\{ \begin{array}{l} \text{Mass of the bob} = 500 \text{ kg.} \\ \text{Period of pendulum oscillation} = 4.2 \text{ sec.} \\ \text{Multiplication} = 70. \end{array} \right.$$

The two horizontal components were set up in the directions of NW—SE and NE—SW.

Time of commencement = 0^h 58^m 51^s.

Total duration, more than 1 $\frac{1}{2}$ ^h.

The motion began with very small movements, becoming well defined after 35 sec. During the first 12^m 7^s, the vibrations were due to the pendulum oscillation, of $T=4.2$ sec. and $2a$'s = 0.09 and 0.16 mm respectively in NW and NE components; the motion being much greater in the latter than in the former-direction. The first 7^m 18^s of this epoch may probably be taken as the 1st preliminary tremor, the remaining 4^m 49^s indicating a much greater motion.

For the next 6^m 53^s, the motion became smaller, on account of the absence of large pendulum oscillations; the amplitude remaining on the whole constant :—

$$T = 6.6 \text{ sec.} \dots \left\{ \begin{array}{l} 2a = 0.024 \text{ mm (NE)} \\ \text{,,} = 0.017 \text{ ,, (NW)} \end{array} \right.$$

$$T = 13.8 \text{ sec.} \dots \begin{cases} 2a = 0.033 \text{ mm (NE)} \\ \text{,,} = 0.021 \text{ ,, (NW)} \end{cases}$$

For the next 4^m 50^s, there appeared slow vibrations :—

$$T = 28.0 \text{ sec.} \dots \begin{cases} 2a = 0.017 \text{ mm (NE)} \\ \text{,,} = 0.017 \text{ ,, (NW)} \end{cases}$$

These were mixed with small movements of $T = 8.6 \text{ sec.}$ For the next 9^m 58^s, the motion was nearly uniform and active :—

$$T = 19.0 \text{ sec., } 2a = 0.036 \text{ mm, in each component.}$$

$$\text{,,} = 9.2 \text{ sec., ,, small.}$$

$$\text{,,} = 11.8 \text{ sec.} \dots \begin{cases} 2a = 0.036 \text{ mm (NE)} \\ \text{,,} = 0.03 \text{ ,, (NW)} \end{cases}$$

For the next 15^m 55^s, the motion was small but more or less distinct :—

$$T = 15.1 \text{ sec.} \dots \begin{cases} 2a = 0.021 \text{ mm (NE)} \\ \text{,,} = 0.014 \text{ (NW)} \end{cases}$$

$$\text{,,} = 10.7 \text{ sec., (small).}$$

Towards the very end :— $T = 13.4 \text{ sec. ; } 22.1 \text{ sec.}$

(ii) Pendolo Orizzontale, NS component :—

$$\begin{cases} \text{Weight of the bob} = 60 \text{ kg.} \\ \text{Period of pendulum oscillation} = 27.2 \text{ sec.} \\ \text{Multiplication. Natural size.} \end{cases}$$

The motion consisted simply of the pendulum oscillations throughout.

42. Colaba, Bombay, India. (Pl. XIV and Pl. XX, the *Publications*, No. 23.)

The Government Observatory. (Director, N. A. F. Moos.)

The following very complete note on the seismic observations at Colaba has kindly been furnished by Mr. N. A. F. Moos.

“ The preliminary tremors of the great seismic disturbance which occurred on the 4th April last, were picked up by the Milne's Seismograph at about 5^h 44.1^m (Bombay time) and by the Colaba Seismograph (N—S) at 5^h 44^m 24^s. There was a short temporary lull after the arrival of the preliminary waves—more clearly indicated by the open diagram of the Colaba Seismograph—and the larger waves followed 3.^m4 later as registered by the Milne's and about 3^m 37^s later as recorded by the Colaba Seismograph.

“ Colaba Seismograph No. 1 (E—W) was unfortunately writing very faintly and was displaced by the first shock of the larger movements and the record is incomplete.

“ It is somewhat difficult to fix the exact time of occurrence of the maximum movement accurately as all the traces marking this phase are more or less blurred on account of the violence of the movement, except in one of the records of the Vertical movement Seismograph. In Milne's Seismograph the traces overlap.

“ Both the seismographs for recording vertical movement have given fairly good records. The ‘float’ record indicates the commencement of the movement at 5^h 44.^m8 and the maximum phase as can be approximately ascertained (the trace is blurred on account of the violence of the movement) at 5^h 49.4^m. This phase as also the commencement, both of which are clearly shown by the ‘Balance’ Seismograph, are recorded exactly at the same time as the former. In the latter record, however, five distinct disturbances with intervals of lull are recorded, the time of the fourth—the largest movement corresponding with that of the maximum phase as indicated by the ‘float’ record. The larger movements of the disturbance continued to affect the Vertical motion Seismographs for about 30 minutes. The trace then runs normally smooth

till 6^h 31.3^m when the 'float' record again shows another disturbance but of much smaller magnitude, which attained its maximum at 6^h 32.8^m and ended at 6^h 37.9^m. Yet a third disturbance of still smaller amplitude commenced at 6^h 45.5^m and ended at 6^h 47.1^m.

"The disturbance as picked up by the Barograph shows the commencement at 5^h 48^m, the maximum effect having been registered in this instrument at 5^h 49.4^m. The change due to the oscillation in the column of mercury corresponds to a fall of .02 inch.

"The pulsation and after tremors of the convulsion as noted by the seismographs continued for about four hours, the last smallest being noted at about 10 hours."

43. Potsdam, Germany.

Royal Geodetic Institute, (Director, Prof. Dr. R. Helmert ; Observer, Prof. Dr. O. Hecker.)

Photographic records from a pair of horizontal pendulums of Rebour type, constructed by P. Stückrath, the magnification being 36. The apparatus was furnished with air damping, whose coefficient was 2.5.

Time of commencement = 0^h 58^m 46^s. Total duration = 5 hours.

(i) **EW Component.** Pendulum Period = 16.2 sec.

1st Preliminary Tremor. Duration = 7^m 16^s. The record consists of the pendulum oscillations mixed with the following vibrations :— $T=5.4$ sec., $2a=0.12$ mm.

2nd Preliminary Tremor, Principal Portion, and End Portion. For the first 4^m 42^s, the motion which was greater at the commencement, consisted of the following two sets of vibrations :— $T=26.9$ sec., $2a=0.34$ mm ; $T=4.7$ sec., $2a=0.18$ mm. For the next 3^m 40^s, the motion was regular, the greatest movement

occurring near the commencement :— $T=21.3$ sec., $2a=0.37$ mm ; $T=4.4$ sec., $2a=0.24$ mm. This epoch probably corresponds to the 1st phase of the principal portion. The vibrations in the next 3^m 11^s, which may correspond to the 2nd phase, was as follows :—

- (i) 2^m 10^s 3 vibrations, of $T=43.3$ sec., $2a=0.47$ mm.
- (ii) 1 1 2 „ „ „ $=30.5$ „ „ „ $=0.33$ mm.

These are mixed with the following two sets of motion :— $T=7.7$ sec., $2a=0.33$ mm ; $T=4.0$ sec. Then, at 1^h 17^m 29^s, the motion became much larger, the vibrations in the successive epochs being as follows.

- (i) 5^m 10^s Motion comparatively small :—
 - (a) 1^m 58^s $T=29.5$ sec., $2a=1.28$ mm.
 - (b) 3 12 „ $=19.2$ „ „ „ $=0.96$ „ .
- (ii) 3^m 17^s Motion largest :— $T=16.4$ sec., $2a=2.5$ mm. This was due evidently to the pendulum oscillation.
- (iii) 11^m 25^s Motion on the whole constant :— $T=14.4$ sec., $2a=1.18$ mm ; $T=20.0$ sec., $2a=1.0$ mm.
- (iv) 17^m 40^s Motion small and nearly constant :— $T=15.8$ sec., $2a=0.57$ mm.
- (v) 15^m 20^s :— $T=15.1$ sec., $2a=0.35$ mm ; $T=24.1$ sec.
- (vi) 13^m 35^s :— $T=18.5$ sec., $2a=0.24$ mm.
- (vii) 16^m 24^s :— $T=17.3$ sec., $2a=0.14$ mm.

Thence the motion gradually decreased.

Those periods given above, which varies between 14.4 and 18.5 sec., are that of the pendulum oscillation. They give the mean value of 16.2 sec., as follows :—

$$\begin{array}{r} T=16.4 \text{ sec.} \\ 14.4 \\ 16.2 \\ 15.3 \end{array} \left. \vphantom{\begin{array}{r} T=16.4 \text{ sec.} \\ 14.4 \\ 16.2 \\ 15.3 \end{array}} \right\}$$

15.1	)
18.5	
17.3	

W_2 The W_2 motion began to appear at $3^h 20^m 31^s$:— $T=20.0$ sec., max $2a=0.13$ mm. At $3^h 25^m 31^s$, the motion became distinctly larger, there being, for the next $4^m 4^s$, the second greatest (absolute) maximum:— $T=24.4$ sec., max. $2a=0.18$ mm. For the next $34^m 20^s$, the motion indicated on the whole very slight variation. Thereafter the vibrations became abruptly small: max. $2a=0.05$ mm.

(ii) **NS Component.** Pendulum period=14.1 sec.

1st Preliminary Tremor. Duration= $6^m 53^s$. The record is very obscure.

2nd Preliminary Tremor, and subsequent phases. The following well defined vibration occurred near the commencement:— $T=13.8$ sec., $2a=0.67$ mm; the motion thence decreasing almost to zero at $1^h 08^m 29^s$. For the next $8^m 50^s$:— $T=11.0$ sec., $2a=0.55$ mm. Then, at $1^h 17^m 39^s$, began large vibrations. For the next $18^m 55^s$:— $T=55.2$ sec., $2a=1.55$ mm. Thereafter the diagram consists entirely of the pendulum oscillations:—

Average period (deduced from 100 vib.)=14.1 sec.

W_2 appeared distinctly first at $3^h 40^m 16^s$; and consisted of the vibrations as follows:— $T=17.8$ sec., $2a=0.08$ mm. The motion continued altogether for an interval of $20^m 20^s$. Towards the very end:— $T=16.6$ sec.

44. Göttingen, Germany. (Pls. XV A and XV B, the *Publications*, No. 23.) R. Geophysical Institute. (Prof. Dr. E. Wiechert.)

The record was furnished by Prof. Wiechert's Astatic Pendulum, with damping arrangement, the mass being 1200 kg. The

indicator-magnification was 160, the proper pendulum periods in the EW and NS components being 15.3 and 15.7 sec. respectively.

Time of Commencement = $0^h 58^m 55^s$. Total Duration = $4^h 40^m$.*

(i) **EW Component.** Pendulum period = 15.3 sec.

The motion indicated in the diagram was very large and caused some confusion of the record from the superposition of successive lines, such that it was impossible to find out the parts corresponding to the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion.

1st Preliminary Tremor. Duration = $7^m 25^s$. The movements in the successive epochs of this portion were as follows.

$$(i) \quad 2^m 0^s \dots \left\{ \begin{array}{l} T = 4.3 \text{ sec. ; } 2a = 3.4 \text{ mm.} \\ \text{,,} = 9.0 \text{ ,, ; ,,} = 8.8 \text{ ,, .} \\ \text{,,} = 18.0 \text{ ,, ; ,,} = - \text{ ,, .} \end{array} \right.$$

The vibrations of the last sort were those due to the pendulum oscillations.

$$(ii) \quad 3^m 50^s \dots \left\{ \begin{array}{l} T = 4.4 \text{ sec. ; } 2a = 5.8 \text{ mm.} \\ \text{,,} = 11.7 \text{ ,, ; ,,} = 7.0 \text{ ,, .} \end{array} \right.$$

(iii) $1^m 35^s$ The motion consisted of pendulum oscillations:—

$$T = 17.3 \text{ sec. ; } 2a = 14.0 \text{ mm.}$$

Principal Portion. During the first $7\frac{1}{2}$ min., when the motion was greatest, the vibrations were as follows:—

$$T = 9.3 \text{ sec. ; } 2a = 113.0 \text{ mm.}$$

For the next 15 min., especially during the first $2\frac{1}{2}$ min, the motion remained active consisting of large pendulum oscillations, as follows:— $T = 16.4 \text{ sec. , } 2a = 102.5 \text{ mm.}$

End Portion. Towards the very end of the earthquake motion

* The range of motion (2a) is given in actual size as traced on the diagrams, not divided by the multiplication ratio.

the period, each deduced from 40 vibrations, was as follows :—

$$\begin{cases} 4 \text{ hours after the commencement of Eq. : } T=17.9 \text{ sec.;} \\ 3 \text{ ,, ,, ,, : ,, =17.0 ,,} \end{cases}$$

The average value of the proper oscillation of the pendulum in the EW direction comes out to be 17.3 sec.

(ii) **NS Component.** Pendulum period=15.7 sec. The NS component record is clear, and the different phases of motion can be identified.

1st Preliminary Tremor. Duration=7^m 8^s. The motion was nearly uniform and consisted of the following two sets of vibrations :—

$$\begin{cases} T=8.5 \text{ sec., } 2a=4.0 \text{ mm;} \\ \text{,,}=4.5 \text{ ,, , ,,} \text{ —} \\ \text{,,}=2.2 \text{ ,, , ,,} \text{ —} \end{cases}$$

2nd Preliminary Tremor. Duration=7^m 40^s.

$$\begin{cases} T=13.4 \text{ sec., } 2a=34.0 \text{ mm;} \\ \text{,,}=10.2 \text{ ,, , ,, =25.0 ,,} \end{cases}$$

Principal Portion. [1st and 2nd phases.] Duration=6^m 35^s. During the first 4^m 50^s, the motion consisted of the following two sets of slow vibrations, mixed with some pendulum movements :—

$$\begin{cases} \text{(i) For } 2^{\text{m}} 25^{\text{s}} : T=48.3 \text{ sec., } 2a=47.0 \text{ mm.} \\ \text{(ii) ,, } 2 \text{ } 24 : \text{,,}=36.0 \text{ ,, , ,, =55.0 ,, .} \end{cases}$$

During the remaining 1^m 47^s, the motion became very large, the period again quickening slightly :— $T=30.6$ sec., $2a=109$ mm.

[3rd phase.] Duration=5^m 55^s. The motion became quicker and large :—

$$\begin{cases} T=11.0 \text{ sec., } 2a=110 \text{ mm.} \\ \text{,,}=15.0 \text{ ,, , (pend. oscillation.)} \end{cases}$$

For the next 5^m 35^s, the motion was smaller, but still active :—

$$\begin{cases} T=9.5 \text{ sec., } 2a=74.5 \text{ mm.} \\ \text{,,}=14.5 \text{ ,, , ,, =112 \text{ ,, , (pend. oscillation.)} \end{cases}$$

For the next 13^m 20^s :—

$$\begin{cases} T = 9.5 \text{ sec.}, 2a = 67 \text{ mm.} \\ \text{,,} = 14.1 \text{ ,, ,,} = 69 \text{ ,, . (pend. oscillation.)} \end{cases}$$

End Portion. The period towards the end of the earthquake was as follows :—

$$\begin{cases} 3 \text{ hours after the commencement of Eqke., } \dots T = 17.8 \text{ sec.} \\ 4 \text{ ,, ,, ,, ,, ,, ,, = 17.5 ,,} \end{cases}$$

W_2 . In the end portion of the W_1 motion, the mean period was 17 sec. At 3^h 20^m there began the W_2 motion consisting of slow vibrations of $T = 25$ sec., the latter decreasing to 20 sec. at 3^h 32^m. After a series of max. and min. groups, a large motion of $2a = 0.07$ mm is reached in the EW component at 3^h 45^m.*

The following tabular statements of the results of the observation is taken from Mr. G. Angenheister's paper: "Seismische Registrierungen in Göttingen im Jahre 1905,"†

Phase of motion.	Times.	T	$2a$		Acceleration (milligal)	
			EW.	NS.	EW	NS
Commencement.	0 ^h 58 ^m 55 ^s	1-4 ^{sec.}	50 ^μ	5 ^μ	—	—
		20-25	40	—	0.2	—
2nd Prel. Tremor.	1 06 08	15	—	200	—	2
		10	—	60	—	1
		15	140	—	1	—
Maximum (NS).	1 19 00	10	400	600	8	12
Maximum (EW).	1 22 00	10	700	700	14	14
Tail (End Portion).	—	17				
End.	5 40					

* This remark on W_2 is based on a note given in Mr. G. Angenheister's "Seismische Registrierungen in Göttingen im Jahre 1905."

† Nachrichten der K. Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse, 1906.

45. Leipzig, Germany. Erdbebenstation. (Director, Prof. Dr. Credner; Observer, F. Etzold.) Wiechert's Astatic Pendulum Seismograph* :—

Pendulum weight = 1100 kg. Indicator-Multiplication = 250.

Pendulum period = 9.2 sec.

Time of Commencement = 0^h 58^m 44^s. Total Duration = 2^h 08.^m

(i) **EW Component.** (Pl. XIV, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration = 7^m 06^s. The motion, which is much more pronounced than in the NS component, began very gradually; the quick vibrations predominating during the first 4^m 25 sec. The period of slow movements was $T=10.7$ sec. The end of this phase was not well marked.

2nd Preliminary Tremor. Duration = 7^m 48^s. For the first 3^m 06^s, the motion was almost similar to that in the latter part of the 1st preliminary tremor, consisting of small quick vibrations mixed with slow ones of $T=10.0$ sec. Then there appeared some slow vibrations, mixed with others, as follows :— $T=48.0$ sec., $2a=3.0$ mm; $T=9.4$ sec., $2a=1.5$ mm; $T=16.2$ sec., $2a=2.8$ mm.

1st and 2nd Phases, Principal Portion. Duration = 8^m 07^s. The motion began with two slow vibrations :— $T=49.2$ sec., $2a=3.0$ mm. Then there followed 5 gradually increasing vibrations :— $T=29.7$ sec., $2a=11.6$ mm. The remainder of these phases consisted of 8 vibrations :— $T=29.4$ sec., $2a=10.0$ mm. The superposed vibrations were :— $T=9.2$ sec., $2a=28.0$ mm, this latter max. movement having occurred at 0^h 23^m. [*3rd phase.*] For the first 4^m 33^s, the motion was most active, the max. vibration having occurred at 1^h 23^m 06^s :— $T=9.1$ sec., $2a=88.0$ mm; $T=29.1$ sec. (?).

* In the following analysis of the seismograms, $2a$ is given in the natural size of the record, not divided by the multiplication ratio.

The subsequent motion was smaller :— $T=9.0$ sec. ; 12.0 sec. ; 21.5 sec. ; 24.3 sec.

(ii) **NS Component.** (Pl. XIV, the *Publications*, No. 23.)

1st Preliminary Tremor. Quick vibrations were mixed with slow ones of periods $T=4.3$ sec., $T=7.9$ sec.,

2nd Preliminary Tremor. Duration= $7^m 25^s$. The commencement of this phase was clearly marked by the appearance of slow large vibrations, which were only slightly shown in the EW component. The first vibration was :— $T=38.0$ sec., $2a=8.5$ mm ; mixed with smaller ones of $T=9.5$ sec., $2a=10.5$ mm. For the next $1^m 56^s$, the motion was small :— $T=14.0$ sec., $2a=1.4$ mm. Then at $1^h 08^m 48^s$, there began again slow vibrations, the first two of which were well defined :— $T=46.9$ sec., $2a=7.0$ mm. Towards the end of this phase :— $T=4.5$ sec. ; $T=13.1$ sec., $2a=4.0$ mm.

Principal Portion. This phase began at $1^h 13^m 31^s$. For the first $3^m 26^s$, the motion was small :— $T=9.7$ sec., $2a=11.0$ mm ; $T=36.6$ sec. For the next $1^m 23^s$, the motion was larger :— $T=8.8$ sec., $2a=37.0$ mm ; $T=37.0$ sec. For the next $7^m 45^s$, the motion was most active, commencing at $1^h 18^m 25^s$ with 2 large vibrations :— $T=8.9$ sec., $2a=67.0$ mm ; mixed with slow one of $T=20.3$ sec. The 2nd max. $2a$ of 59.5 mm occurred at $1^h 25^m 04^s$, and during the interval between these two epochs, there were 7 sub-maxima, the first 6 of which occurred at nearly regular intervals of $1^m 18^s$ (average).

For the next $5^m 23^s$, the motion was smaller :— $T=11.0$ sec., $2a=27.5$ mm ; $T=22.7$ sec. For the next $4^m 45^s$, the motion became again smaller :— $T=21.6$ sec., $2a=14.0$ mm. The subsequent motion was still smaller :— $T=22.8$ sec., $2a=8.0$ mm ; $T=9.3$ sec.

The following tabular statement of the elements of motion is taken from Mr. F. Etzold's 6th Report on the Leipsic Seismic Observation.*

Phase of motion	Times.	<i>T</i> .	2 <i>a</i> (NS)	2 <i>a</i> (EW).
Commencement.	0 ^h 58 ^m 44 ^s	1 sec. 4	4-8 ^μ 7	4-10 ^μ 11
2nd Prel. Tremor.	1 05 53	12	60	
„ (NS).	1 08 48	ca. 55	930	
Long Waves.	1 13 30			
Prominent Vibration (EW).	1 23 05	13		600
„ „ (NS).	1 18 27	9	211	
„ „ (EW).	1 26 55	12		213
„ „ (NS).	1 23 14	12	322	
„ „ (NS).	1 25 58	10	256	
Tail, or End Portion.		24-8		
End.	3 06 15			

46. Upsala, Sweden, (Pl. XVI, the *Publications*, No. 23).

Meteorological Observatory. (Director, Prof. Hildebrandsson. Observer, Filip Akerblom).

Wiechert's Astatic Pendulum Seismograph* :—

Weight of the heavy mass = 1000 kg.

Indicator-Multiplication = 235.

Pendulum period = about 9 sec.

Relaxation time = about 5 sec.

Commencement = 0^h 58^m 22^s. Total Duration = 3^h 7^m.

(i) NS Component.

1st Preliminary Tremor. Duration = 6^m 51^s. The motion began

* Berichte der Mathematisch-physikalischen Klasse der königlich sächsischen Gesellschaft der Wissenschaften zu Leipzig. LVIII. Band.

* 2*a* is given in the natural reading, not divided by the multiplication ratio.

with very small but distinct vibrations of $T=5.2$ sec., which in 35 sec. gradually reached a max. $2a$ of 8.6 mm. At first there were also some small quick movements.

For the next $1^m 34^s$, the motion was small :— $T=6.5$ sec.; $T=2.5$ sec. Then there took place the 2nd max. group, consisting of 2 conspicuous vibrations, as follows :— $T=5.0$ sec., $2a=19.0$ mm. During the whole remainder of this phase, the motion was nearly constant :— $T=4.5$ sec., $2a=8.0$ mm ; $T=9.1$ sec.

2nd Preliminary Tremor, etc. The 2nd preliminary tremor began with a max. group, which lasted 44 sec. :— $T=8.9$ sec., $2a=24.0$ mm. The movements during the successive epochs were as follows :—

(i) $2^m 18^s$. . . Motion small :—

$T=8.7$ sec., $2a=8.0$ mm ; $T=5.7$ sec., $2a=10.0$ mm

(ii) $3^m 45^s$. . . Motion larger :—

$T=6.9$ sec., $2a=47.0$ mm ; $T=13.2$ sec.

(iii) $4^m 18^s$. . . Motion again larger :—

$T=8.4$ sec., $2a=66.0$ mm ; $T=15.9$ sec.

Then the motion became very large, commencing with one of $T=13.4$ sec. The subsequent vibrations became quicker and gradually increased in amplitude :— $T=9.6$ sec., $2a=181.0$ mm (max. limit). The pointer then went off the smoked paper.

(ii) EW Component.

1st and 2nd Preliminary Tremors. The motion began with small vibrations, which reached a maximum 17 sec. after the start, thence again decreasing :—

$T=7.3$ sec., $2a=10.5$ mm ; $T=3.7$ sec., $2a=4.5$ mm ; $T=2.5$ sec. (?)

The 2nd max. occurred $2^m 9^s$ after the commencement :— $T=8.4$ sec., $2a=28.0$ mm. The subsequent motion was small :— $T=3.8$ sec., $2a=12.0$ mm.

The 3rd max. occurred $6^m 50^s$ after the commencement and consisted of $4\frac{1}{2}$ vibrations, lasting for 45 sec.;— $T=10.1$ sec., $2a=30.6$ mm.

The motion for the next successive epochs were as follows:—

(i) $3^m 06^s$. . . Motion small:—

$$T=4.9 \text{ sec.}, 2a=15.0 \text{ mm}; \quad T=12.1 \text{ sec.}$$

(ii) $2^m 39^s$. . . Motion larger and slower:—

$$T=14.5 \text{ sec.}, 2a=33.0 \text{ mm}(?); \quad T=7.8 \text{ sec.}, 2a=34 \text{ mm.}$$

(iii) $4^m 41^s$. . . Motion much greater:—

$$T=7.3 \text{ sec.}, 2a=50.0 \text{ mm}; \quad T=5.5 \text{ sec.}, 2a=30.0 \text{ mm};$$

$$T=12.7 \text{ sec.}, 2a=38.5 \text{ mm.}$$

3rd Phase, Principal Portion. For the first $3^m 58^s$, the motion was most active, comprising the following three max. groups:—

1st group $T=9.1$ sec., $2a=200$ mm.

2nd „ $T=8.7$ „ „ „

3rd „ $T=13.4$ „ „ $2a=205$ mm (max. limit.)

During the next $12^m 32^s$, the successive max. movements gradually diminished from 198.0 mm to 46.0 mm; the first 5 max. vibrations were conspicuous and occurred at nearly regular intervals, as follows:—

$$\left\{ \begin{array}{l} \text{Interval between 1st and 2nd max.} = 1^m 39^s. \\ \text{„} \quad \quad \quad \text{2nd „} \quad \text{3rd „} = 1 \quad 52 \\ \text{„} \quad \quad \quad \text{3rd „} \quad \text{4th „} = 2 \quad 05 \\ \text{„} \quad \quad \quad \text{4th „} \quad \text{5th „} = 1 \quad 38 \end{array} \right.$$

The period of the principal vibrations in the max. group was:— $T=9.7$ sec. But at min. places there were the following slow movements:— $T=13.8$ sec.; $T=21.5$ sec.

For the next $10^m 10^s$, the motion was much smaller and nearly uniform, there being 7 maxima which occurred at nearly regular intervals of $1^m 41^s$ (average). These maxima ranged between 16.0 (1st max.) and 21.5 mm (5th max.), and the period was $T=$

12.2 sec. At min. epochs there were also some vibrations of $T=22.3$ sec. ; $T=8.7$ sec.

Thereafter the motion was much smaller :— $T=11.2$ sec., $T=26.6$ sec. Towards the end of the earthquake :— $T=14.8$ sec.

The following tabular statement of the elements of motion is taken from Mr. F. Akerblom's Report on the seismic observations at Upsala, Oct. 1904 to May 1905.*

Phase of motion.	Times.	T	$2a(\text{EW})$	$2a(\text{NS})$
Commencement.	0 ^h 58 ^m 22 ^s	1.5 ^{sec.}	5 ^μ	1 ^μ
		5	35	30
Increase of motion.	1 00 31	5	90	60
2nd Preliminary Tremor.	1 05 19	7	80	60
		15		
Long Waves.	1 12.6			
Prominent Vibration.	1 17.4	9	600	540
"	1 20.2	9	620	
Tail (End Portion).		16		
End.	4 05			

47. *Batavia, Java.*

The Royal Magnetic and Meteorological Observatory. (Director, Dr. S. Figee. Vice Director, Dr. W. van Bemmelen.)

EW Component motion photographically registered by a Rebeur-Ehlert Horizontal Pendulum, whose oscillation period was 9.8 sec., and whose period, when suspended vertically, was 1.32

* Nachrichten der K. Gesellschaft der Wissenschaften zu Goettingen. Math.-physik. Klasse. 1906.

seconds, so that 1 mm displacement on the photogram would correspond to a tilt of $0''.159$.

Time of commencement = $0^h 58^m 33^s$. Total duration = $3^h 50^m$.

1st Preliminary Tremor. Duration = $7^m 0^s$. The motion consisted chiefly of the following 3 sets of vibrations :— $T=5.9$ sec. ; $T=9.8$ sec. ; $T=1.4$ sec. The last period characterizes movements of a macroseismic nature. Then set in large pendulum oscillations, which remained active till about $1^h 48^m$, the motion thence gradually diminishing,

In the epoch, which may correspond to the 1st and 2nd phases of the principal portion, there were some large slow vibrations of $T=18.8$ sec., mixed with pendulum oscillations. For the next $19^m 3^s$, the motion was large, as follows :— $T=11.4$ sec., max. $2a$ (actual record) = 57 mm.

For the next 10 m., the motion, which was smaller, was as follows :— $T=10.0$ sec., max. $2a$ (actual record) = 18.5 mm. Towards the very end, $T=9.4$ sec.

The different values of the period above given, nearly equal to 10 sec., are due to the pendulum oscillation ; these are

$$\left. \begin{array}{l} 9.8 \text{ sec.} \\ 11.4 \\ 10.0 \\ 9.4 \end{array} \right\} \text{mean, } 10.2 \text{ sec.}$$

The trace of the W_2 motion was not indicated, probably on account of the shortness of the free oscillation of the pendulum.

Pulsatory Oscillations.

The diagram indicated small pulsatory oscillations, both before and after the earthquake. Their periods, deduced from 5 series, each of 80 vibrations, were as follows :—

Before the earthquake . . .	{	7.4 sec.
		7.5
		8.0
		7.3
After the earthquake		7.6
<i>Mean</i>		7.6 sec.

This corresponds to what I have denoted by Q_2 . (See § 8).

48. Zikawei, (Shanghai), China : Observatory (Director, L. Froc). **Rio de Janeiro**, Brazil : Observatorio do Rio de Janeiro (Director, H. Morize). The seismic records at these two places, furnished by the Omori horizontal pendulums, were not satisfactory.

Strassburg, Germany : Kaiserliche Hauptstation für Erdbebenforschung (Director, Prof. Dr. G. Gerland). The copies of the diagrams furnished by Rebour-Ehlert horizontal pendulum and the Vicentini microsismografo were not clear enough to allow us to study them in detail.

The times of the earthquake occurrence at the above mentioned 3 places have been given in Table I.

49. Earthquake Observations at Taschkent, Irkutsk, Tiflis, Achalkalaki, Batum, Borskom, Derbent, Schemacha, Furjew (Dorpat), Nikolajew, Belgrade, Krakau, Jena, Hamburg, Padova, Messina, Apia, Vieques. The results of the earthquake observations at these 18 stations, given in tabular form in §§ 37–53, are taken from the different seismological periodical reports.

50. Taschkent, Russian Turkestan.

Astronomical and Physical Observatory. (Observer, J. Goul-tiaeff.)

The times of the different parts of the earthquake motion recorded by Omori seismographs and a Rebour-Ehlert pendulum were as follows.*

(In Taschkent Time)	Omori			Rebour-Ehlert	Mean (G. M. T.)		
Commencement of Eq.	^h 5	^m 29	^s 35	^h 5	^m 29.6	^h 0	^m 52 ^s 24
„ of 2nd prel. tremor.	5	31	37	5	31.7	0	54 29
Maximum motion.	5	34	33			0	57 22
End	—			10	4.2	5	27 00

Thus the duration of the preliminary tremor was 2^m 5^s.

After-shocks. The areual distance between the earthquake origin and Taschkent was only 1260 km and it is possible that the shaking was actually felt at the latter place. In the course of the succeeding two days, the seismographs there recorded 11 small seismic disturbances, as shown in the following list.

Date.	Time of Commencement.†	Time of Maximum.†	Time of Com- mencement (G. M. T.)	Max. 2a
April 4th.	^h 12 ^m 31.6	^h 12 ^m 31.6 (NS)	^h 7 ^m 54 ^s 25	^{mm} 2.0
	13 4.0	13 4.0 (EW)	8 26 49	2.8
	13 19.6	13 19.6 (EW)	8 42 25	2.5
	14 12.7	14 12.7 (EW)	9 35 31	2.0
	15 10.0	15 10.0 (EW)	10 32 49	2.4
	15 24.9	15 27.9 (EW)	10 47 43	4.0

* Taken from Monatsberichte der Horizontalpendel Station am Astronomischen und Physikalischen Observatorium zu Taschkent. No. 4, 1905.

† Taschkent Time.

Date.	Time of Commencement.	Time of Maximum.	Time of Commencement (G. M. T.)	Max. 2a
	^h ^m 15 51.9	^h ^m 15 51.9 (EW)	^h ^m ^s 11 14 43	^{mm} 3.3
April 4th.	17 14.9	17 14.9 (NS)	12 37 43	10.2
	22 9.3	22 9.3 (NS)	17 32 07	2.0
	23 16.1	23 19.7 (NS)	18 38 55	3.5
April 5th.	3 44.6	3 47.0 (EW)	(April 4th) 23 07 25	5.8

51. *Irkoutsk*, Siberia.*

L'Observatoire Magnétique et Météorologique. (Directeur, A. Voznessensky).

Instrument.	Commencement.	Increase of motion (or minimum).	Maximum.	End (or weakening)	2a
	^h ^m 0 55.7	^h ^m —	^h ^m 0 57.3	^h ^m —	^{mm} 42.0
	—	—	0 58.3	—	75.0
Zöllner-Repsold	—	1 1.1	1 02.9	—	176.4
Pendulum. NS.	—	—	1 07.0	—	202.0
	—	3 20.6	3 28.6	—	22.8
	—	—	3 43.6	—	22.8
	—	—	4 11.9	8 16	20.0
	0 55.7	—	0 56.9	—	31.6
	—	1 00.8	1 01.0	—	78.0
Zöllner-Repsold	—	—	1 01.6	—	227.2
Pendulum. EW.	—	—	1 05.7	—	226.0
	—	3 09.8	3 17.2	—	20.0
	—	—	3 44.6	8 09	28.8

* See Bulletin de la Commission Centrale Sismique Permanente. Année 1905, Avril-juin. St.-Petersbourg.

Instrument.	Commence- ment.	Increase of motion (or minimum).	Maximum.	End (or weakening)	2a
	h m	h m	h m	h m	mm
Milne Hor. Pendulum. NS.		0 55.7	—	—	4.0
		—	0 56.7	—	4.6
		—	1 00.7	—	26.0
		—	1 05.7	—	40.0
		—	—	—	>40.0
		—	—	—	15.6
		—	1 25.3	—	22.4
		—	—	—	10.0
		—	—	1 48	8.8
		—	—	2 27	—
		—	—	>2 36	—
	0 55.8	0 56.1	—	—	—
Omori Horizontal Pendulum. NS.	—	1 00.8	1 01.0	—	12.0
	—	—	1 01.2	—	25.0
	—	—	1 01.6	—	54.8
	—	1 05.0	1 07.2	—	60.0
	—	—	1 08.3	—	104.0
Omori Horizontal Pendulum. EW.	0 55.8	1 00.9	1 01.5	—	28.0
	—	1 05.3	1 06.1	—	36.0
	—	—	1 06.8	—	66.0
	—	—	1 07.2	1 08	88.0
	—	1 21.1	—	2 17	—

The mean time moments of the different phases and the duration of the 1st preliminary tremor are as follows :—

Time of Eq. Commencement, t_1 , = 0^h 55^m 46^s
Commencement of 2nd Prel. Tremor, t_2 , = 1 00 52
Duration of the 1st Prel. Tremor, y_1 , = 5^m 06^s

52. Tiflis, Achalkalaki, Batum, Borshom, Derbent, Schemacha, Caucasus, Russia. Tiflis : Physical Observatory, (Director, S. v. Hlasek ; Assistant, P. E. Stelling).

The positions and the results of the observations at Tiflis and the above named 5 adjacent stations are given in the following tables*

Place.	ζ	λ
Tiflis	41° 43' 8" N	44° 47' 51" E
Achalkalaki	41 25	43 29 09
Batum	41 40	41 38 35
Borshom	41 51	43 23 08
Derbent	42 04	48 18
Schemacha	40 38	48 38

Observations at Tiflis.

(Tiflis time.)

Instrument.	1st Preliminary Tremor.	2nd Prel. Tremor.	End.	Max. Motion.
	^h ^m ^s	^h ^m ^s	^h ^m	^h ^m ^s
R.E. { facing W 30° S	3 54 57	—	—	—
" N	3 55 03	—	—	—
" E 30°	3 55 00	—	—	—
Milne, " S	3 55 00	42 ^s	9 —	13 ^m 00 ^s 31.6 ^{mm}
Omori { " N	3 54 54	46	6 30	8 26 11.7
" E	3 55 10	32	8 —	? >48.
Zoellner { " N	3 54 54	50	6 30	13 18 6.5
" E	3 55 06	34	8 —	9 50 30.6
Omori { " N	3 54 52	52	7 30	13 34 22.7
" E	3 54 48	28	—	9 42 35.2
Cancani { in meridian.	3 55 00	57	5 —	5 06 9.4
in prime vertical	3 55 00	38	—	0 49 26.8

* Taken from *Seismische Monatsberichte des Physikalischen Observatoriums zu Tiflis*. No. 4, 1905.

Increase of motion (or minimum).	Maximum.	End (or Weaken- ing).	2a
1 ^h 04.5 ^m	2 ^h 17.2 ^m	— ^h — ^m	29.0 ^{mm}
—	2 27.8	—	11.5
—	2 38.9	—	13.5
—	2 49.2	—	9.8
—	3 48.6	—	9.0
—	3 53.8	—	10.0
—	4 02.1	—	8.0
—	4 06.2	—	9.5
—	4 10.8	—	8.1
—	4 21.7	4 32	7.4

54. Jurjew (Dorpat), Russia.*

Astronomical Observatory, University of Jurjew. (Professor G. Levitsky).

Instrument.	Commence- ment.	Increase of motion (or minimum).	Maximum.	End (or Weaken- ing.)	2a.
Zöllner-Repsold Pendulum E-W.	0 ^h 57 ^m 54 ^s	1 ^h 04 ^m 00 ^s	1 ^h 05 ^m 05 ^s	— ^h — ^m — ^s	80 ^{mm}
		1 12 49	—	—	—
		1 48 41	—	—	—
		2 01 41	—	2 24 19	—
		2 45 12	—	—	—
		3 03 50	—	—	—
		3 22 22	—	—	—
		3 31 36	—	—	—
		3 40 21	—	6 05 00	—

* Taken from *Bulletin de la Commission Central Sismique Permanente*, Année 1905, Avril-juin. St. Pétersbourg.

Instrument.	Commence- ment.	Increase of motion (or minimum).	Maximum.	End (or Weaken- ing.)	2a.
	^h ^m ^s 0 57 50	^h ^m ^s 1 04 57	^h ^m ^s 1 17 00	^h ^m ^s —	^{mm} 328
Zöllner-Repsold		1 42 09	—	—	—
Pendulum		2 17 48	—	—	—
N-S.		2 36 42	—	2 55 39	—
		3 03 59	—	—	—
		3 36 31	—	5 50.4	

55. Belgrade, Serbia.

R. Astronomical and Meteorological Observatory. (Prof. M. Nedelkovitch).

The time of Eqke commencement = $0^h 57^m 47^s$.

56. Krakau, Austria-Hungary.

I. R. Astronomical Observatory. (Prof. M. Rudzki.)

The following table, taken from the Krakau earthquake report, gives the elements of motion as recorded by an Omori horizontal pendulum set up in the SE direction, whose natural oscillation period was about 26 sec., and whose magnification was about 10.

Commencement.....	^h ^m ^s 0 58.2
2nd prel. tremor	1 3.8
1st max. group	1 14.3—23.3 (^m 2a=19.5 mm)
2nd „ „	1 29.5—32.1 („ „ 17.5 „)
3rd „ „	2 0.4— 1.4 („ „ 8.0 „)
End portion	2 29.4
End	3 30.0

57. Jena, Germany.*

Seismische Station, Astronomisches Observatorium. (Director, Prof. O. Knopf; Assistant, Dr. O. Eppenstein.)

Wiechert's Pendulum, of the following constants:—

Doppelte Schwingungsdauer bei möglichst kleiner Dämpfung,

T_0^{sec.}11.6 (EW) ; ^{sec.}11.2 (NS).

Indikatorvergrößerung V 171 „ ; 183 „

Maximaler Reibungsausschlag γ 0.7 „ ; 0.5 „

Dämpfungsverhältnis ϵ 4.9 „ ; 4.9 „

Phase of Motion.	Times.	T	$2a$ (EW)	$2a$ (NS)
	h m s			
Commencement.	0 58 54	{ ^{sec.} ca 1 7—9	0.5 μ 50	0.5 μ 24
2nd Prel. Tremor.	1 06.1	11		140
Long Waves (NS).	1 16.0	12		340
	1 18.7			Over 580
Increase of Motion.	1 1.1	(Similar to the first shock)		(Here the NS com- ponent po- inter was thrown out)
	1 5.5	13	45	
Long Waves (EW)	1 16.3	9	140	
Prominent Vibration (EW)	1 23.4	13	790	
„ „ „	1 26.2	11	580	
	1 42.9— ^m 45.9	15	160	
Tail (or End Portion)	2 22	15 20 30		
End.	5 30			

58. Hamburg, Germany.†

Hauptstation für Erdbebenforschung am Physikalischen Staatslaboratorium. (Dr. R. Schütt.)

Dreifaches Horizontalpendel of Rebeur-Ehlert.

* *Monatliche Erdbebenberichte der Seismischen Station zu Jena.* April, 1905.

† *Mitteilungen der Hauptstation für Erdbebenforschung am Physikalischen Staatslaboratorium zu Hamburg.* April, 1905.

Phase of motion.	Times.	2a
Commencement.	^h 0 ^m 58 ^s 14 (Pend. N.)	---
2nd Prel. Tremor.	1 02 23 (Pend. M.)	---
Principal Portion.	1 05 47 (")	---
End.	5 28	---

{ Pendulum N is directed towards S 15° W.
 { " M " " E 15° N.

59. Padova. Italy.*

Istituto di Fisica del R. Università di Padova. (Director, Prof. G. Vicentini; Assistants, Dr. R. Alpago and Dr. G. Abetti.)

The motion was recorded by three Microsismografo "Vicentini," A, B, and E, whose instrumental constants were as follows.

(A.) Two horizontal components :—

{ Length of Pendulum = 10.68 m.
 { Mass = 400 kg.
 { Oscillation period = 6.3 sec.
 { Multiplication = 89.
 { Velocity of the smoked paper = 20 mm per minute.

(B.) Vertical and two horizontal components :—

Horizontal Components.	Vertical Component.
{ Length of Pendulum = 1.50 m.	{ Length of Spring = 1.32 m.
{ Mass = 100 kg.	{ Mass = 45 kg.
{ Oscillation period = 2.3 sec.	{ Oscillation period = 1.2 sec.
{ Multiplication = 129.	{ Multiplication = 167.
{ Velocity of the smoked paper = 8.5 mm per minute.	

* See Cenno Preliminare sulle RegISTRAZIONI dei Microsismografi dell' Istituto di Fisica della R. Università di Padova. 1905.

(E.) Vertical and two horizontal components :—

<i>Horizontal Components.</i>	<i>Vertical Component.</i>
Length of Pendulum = 1.50 m.	Length of Spring = 1.29 m
Mass = 100 kg.	Mass = 50 kg.
Oscillation period = 2.4 sec.	Oscillation period = 0.8 sec.
Multiplication = 101.	Multiplication = 270.
Velocity of the smoked paper = 15 mm per minute.	

Microsismografo A.

Phase of motion.	Time.	Max. 2a.	T.
Commencement.	^h 0 ^m 59 ^s 02 (EW)	— mm	— sec.
	1 06 48 (NS)	72	—
	1 06 52 (EW)	75	—
End of first phase.	1 40 30 ca.	—	38
Slow vibration epoch.	1 43 00	—	16-12
End.	4 05 ca.	—	

Microsismografo B.

Phase of motion.	Vertical Component.			Horizontal Component.		
	Times.	Max. 2a.	T.	Times.	Max. 2a.	T.
Commencement.	^h 0 ^m 58 ^s 56	mm	sec.	^h 0 ^m 59 ^s 00	mm	sec.
	0 59 51	1.7	3.2			
	1 06 27	Small.	4.7	1 06 33	5.2	5.3
				1 17 20		8.5
	1 19 20	Very small	8.0	1 24 20		12.5
						20-10
End.	2 28 00			4 05 00		

Microsismografo E.

Phase of motion.	Vertical Component.			Horizontal Component.		
	Times.	Max. $2a$.	T	Times.	Max. $2a$.	T
Commencement.	^h ^m ^s 0 58 57	mm	sec.	^h ^m ^s 0 58 57	mm	sec.
	1 00 04	5.0		1 01 23	30.2(EW)	
	1 04 ca	{ End of pend. motion phase.		1 12 10		4.0
	1 16 52	Oscillations.	11.0	1 15 ca	{ Oscilla- tions.	4.8
				1 17 15	„	7.1
	1 21 12	Very small.	9.2			
End.		Slow oscil.	Varying		Slow oscil.	Varying
	2 ca			3 10 ca		

From the above table, we obtain the following mean results :—

$$\left\{ \begin{array}{l} \text{Time of Commencement of the 1st Prel. Tremor} = t_1 = 0^h 58^m 58^s. \\ \text{„ „ „ 2nd „ „} = t_2 = 1^h 06^m 42^s \\ \text{Duration of the 1st Preliminary Tremor} = y_1 = 7^m 44^s. \end{array} \right.$$

60. Messina, Italy. Institute of Terrestrial Physics, Royal University (Prof. G. B. Rizzo).

Sismografo “Agamennone” a due componenti; Pendulum Period=3.9 sec.

The observation was as follows.*

Phase of motion.	NE-SW Component.			NW-SE Component.		
	Time of Commencement.	T	$2a$	Time of Commencement.	T	$2a$
1st Prel. Tremor.	^h ^m ^s 0 59 00	sec.	mm	^h ^m ^s 1 05 24	sec.	mm
2nd „ „	1 06 15	10.9	0.7	1 07 36	6.0	0.7

* See the *Annuario dell'Anno 1905, Osservatorio di Messina.*

Phase of motion.	NE-SW Component.			NW-SE Component.		
	Time of Commencement.	T	$2a$	Time of Commencement.	T	$2a$
	^h ^m ^s	^{sec.}	^{mm}	^h ^m ^s	^{sec.}	^{mm}
Princ. Portion.	1 15 42	—	—	1 15 55	—	—
Max. Phase.	1 25 07	15.6	2.6	1 26 50	16.0	0.6
Next Phase.	1 38 25	—	—	1 39 00	—	—
End	2 02	—	—	1 40	—	—

61. *Apia*, Samoa Island.

Samoa Observatory of the Göttingen Academy of Sciences (Dr. F. Linke.) Wiechert's Astatic Pendulum.

The following analysis is taken from the Samoa earthquake report, No. 6, 1905.

Phase of motion.	Time of Commencement.	T	Max. $2a$	
			N-S.	E-W.
	^h ^m		^{mm}	^{mm}
1st preliminary tremor.	1 1.6	(?)	—	—
2nd „ „	1 19.3	17 sec.	0.08	0.09
Large movements.	1 40.	44	0.65	0.65
Maximum vibration.	1 50.	27	0.75	0.55
Tail (End portion).	—	18	—	—
End.	6 00.	—	—	—

62. *Vieques*, Porto Rico.

U.S. Coast and Geodetic Survey Magnetic Observatory. (Superintendent, Dr. Tittmann ; Observer, P. H. Dike.)

Two Omori horizontal pendulums, recording the EW and NS components, are mounted in the north-east room of the ground floor of the old Spanish Fort "Isabel" on Vieques Island just

east of the Island of Porto Rico. The instruments are placed on stone piers laid in cement extending 30 inches below the level of the floor. They are about 130 feet above sea level. The result of the observation was as follows.*

Phase of Motion.	NS Component. (Time of Commencement)	EW Component. (Time of Commencement)
1st Prel. Tremor.	1 ^h 10 ^m 26 ^s	1 ^h 10 ^m 25 ^s
Principal Portion.	1 50 48	1 43 25
Maximum.	2 10 48 ($2a=1.2$ mm)	2 13 51 ($2a=1.6$ mm)
End.	3 47 26	3 38 25

Chapter III. Milne Horizontal Pendulum Diagrams of the Kangra Earthquake.

63. Milne Horizontal Pendulum Stations. The present Chapter contains descriptions of the Milne Horizontal Pendulum Seismograms obtained at the following 19 stations :—Shide ; Kew ; Liverpool (Bidston) ; Edinburgh ; Paisley ; San Fernando ; Wellington ; Christchurch ; Mauritius ; Cape of Good Hope ; Toronto ; Victoria, B.C. ; Baltimore ; Calcutta ; Kodaikanal ; Bombay (Colaba) ; Bairût ; Ponta Delgada ; Honolulu. The analysis has been made of the photographic copies, except in the cases of the 3 last places whose diagrams I have not received. The reproduction of the registers are given in Pls. XVIII to XXII, the *Publications*, No. 23.

* Reproduced from Professor Reid's paper given in the *Terrestrial Magnetism and Atmospheric Electricity*.

The Milne horizontal pendulums are, according to the instructions from the British Association, usually so placed that the boom is in the meridian or points N-S, the natural oscillation period being about 15 sec. The magnification with respect to the horizontal earthquake motion is 6 to 7 times.

64. Utility of Milne Horizontal Pendulum. The Milne Horizontal Pendulum has rendered an invaluable service to the development of Seismology, a science practically founded on its modern basis by Professor John Milne, who pursues the subject with indefatigable energy and zeal. The instrument is simple in construction, and enables us to see some interesting features in the earthquake motion, which are not so obviously shown by other seismographs. In the present case, the records obtained at 5 British stations, San Fernando, Christchurch, Wellington, and some other places are very satisfactory.

65. Time of Occurrence and Duration. The times of occurrence of the different phases and the total duration of the Kangra earthquake of April 4, 1905, observed at the different stations, as given in Professor Milne's Circular, No. 13, are contained in the following table.

TABLE VIII. Indian Earthquake of April 4, 1906, observed with Milne Horizontal Pendulums.

(Extract from Professor Milne's Circular, No. 13.)

Station.		P. T. Commence.	Max.	Max. Amplitude.	Duration.
Slide.	(B)	^h 1 ^m 1.0	^h 1 30.0	15.0 ^{mm} - a	^h 3 55 ^m (2nd max. 1 ^h 54 ^m later)
"	(C)	^h 1 ^m 6.2	^h 1 22.7	13.0	^h 3 45 (2nd max. 2 ^h 9 ^m & 2 ^h 14 ^m later)

(B: period 25 sec.; C: period 20 sec.)

Station.	P. T. Commence.	Max.	Max. Amplitude.	Duration.
Kew Observatory.	1 ^h 0.2 ^m	1 ^h 29.2 ^m	15.3 ^{mm}	3 48
Liverpool Ob., Bidston.	0 58.8	1 30.6	11.6	4 22
Royal Ob., Edinburgh.	1 0.0	1 31.5	16.0	3 43
The Coats Ob., Paisley.	1 0.4	1 30.7	>14.0	3 40
San Fernando.	1 2.5	1 34.0	8.75	3 45½
Ponta Delgada, St. Miguel, (Azores.)	1 1.0	1 54.5	2.3	2 32½
Royal Ob., Cape of G. H.	1 2.0	1 46.0	3.0	2 10
Alipore Observatory.	0 52.	?	?	3 39
Bombay (Colaba).	0 52.9	—	—	4 19.6
Kodaikanal.	0 55.6	—	>22.0	3 36
Batavia.	0 58.6	1 1.9	7.0	3 —
Baltimore.	1 15.0(?)	2 10.0	3.0	
Beirût, Syria.	0 58.0	1 24½	18.5	3 59
Toronto.	1 14.0(?)	1 54.3	4.0	3 25.8
Victoria, B. C.	1 14.0	1 51.1	6.3	3 26.3

In the analysis of the Milne horizontal pendulum record, the period of vibration has been measured, in several cases, by the use of a magnifying lens. The *2a* always denotes the motion as actually traced on the photograph.

66. British Stations and San Fernando. For the sake of comparison let us first describe the seismographs obtained at the 5 British stations of Shide, Kew, Bidston, Edinburgh, and Paisley, and the Spanish station of San Fernando. The records at these places are given in Pls. XVIII and XIX, the *Publications*, No. 23.

67. Shide, Newport, Isle of Wight, England.

(Professor J. Milne, F.R.S. Assistant, S. Hirota).

The earthquake was recorded by two instruments *B* and *C*, of the following constants :—

B. Period = 25 sec. 1° turn = 9 mm.

C. Period = 20 sec.

C pendulum is without a calibrating screw.

B records N. S. motion, while *C* records E.W. motion.

Horizontal Pendulum B. Commencement = 1^h 1.0^m. In the strongest part, $T = 26.0$ sec. (pendulum oscillations), the max. trace of 22 mm having occurred at 1^h 30.0^m. The motion was more or less active till 2^h 34.5^m, becoming thereafter very small, till the commencement of the W_2 group.

The latter first appeared at 3^h 4.6^m and the max. trace of 2.5 mm was gradually reached at 3^h 23.4^m; there being in the interval altogether 6 max groups, at an average interval of about 3^m 52^s. The W_2 motion may be regarded as having lasted about 54^m.

A slight thickening of the line at about 4^h 37^m may correspond to the W_3 motion.

Hor. Pendulum C. Commencement = 1^h 6.2^m. In the strongest portion, $T = 21$ sec. (pendulum oscillations), the max. trace of 27 mm having occurred at 1^h 22.7^m. The motion was more or less active till 2^h 40^m, becoming thereafter much smaller.

The diagram is somewhat different from that described above, especially in the W_2 group, which first began at 3^h 8.6^m. For the next 12^m 24^s, the motion was small and doubtful. Then, at 3^h 20^m 24^s, there occurred a small maximum (which is marked *a* in the diagram). For the next 27^m the motion was well defined and consisted of a number of max. movements (marked

b, c, d, e, f). These small groups, *a* to *f*, can be identified in the B-pendulum record, although the amplitudes differ much in the two diagrams. The greatest $2a$ of 3.6 mm took place at 3^h 38.7^m. For the next 14^m 30^s, the motion was much smaller but nearly constant, the W_2 group having lasted altogether 1^h 6^m.

The W_3 group occurred at about 4^h 32.5^m.

68. Kew, England. National Physical Laboratory, Kew Observatory. (Director, R.T. Glazebrook, D. Sc., F.R.S.; Superintendent, C. Chree, LL. D., F.R.S.; Observer, E. G. Constable.)

Commencement=1^h 0.2^m. Total Duration=3^h 48.1^m.

1st and 2nd Preliminary Tremors. The entire Duration=13.6^m. For the first 4.5^m the motion was very small. Then the motion increased slightly and remained nearly constant for the next 4.2^m. During the remaining 4.9^m the motion was again slightly larger, there being 4 maximum groups, which occurred at an average interval of 1^m 38.

Principal and End Portions. For the first 1.5^m the motion gradually swelled up to a max. $2a$ of 3.5 mm, being the result of the proper oscillations of the pendulum. For the next 1.5^m the motion was small. For the next 4.0^m the motion was larger, the max. $2a$ of 4.4 mm occurring at the commencement.

For the next 2.6^m the motion was smaller; there being several minimum epochs, probably due to the appearance of slow vibrations, which prevented the pendulum from swaying into the proper oscillation. The time of commencement of this phase was 20.2^m after the beginning of the earthquake.

Then, at 1^h 23.2^m, there appeared a maximum group, which lasted 5.9^m and was composed of 2 subdivisions. This was followed by a minimum, and then by the absolute maximum

group, which lasted 3.0^m and whose greatest $2a$ of 30.6 mm occurred at $1^h 29.2^m$.

Thereafter the motion was much smaller and remained for the next 28.6^m on the whole constant; there being 7 max. groups, whose average interval was 4.1^m and of which the 3rd one had the greatest $2a$ of 13 mm. For the next 7.0^m , the motion was smaller:—max. $2a=3.0$ mm. For the next 21.8^m the motion was again larger (max. $2a=8$ mm); there being a series of maximum groups. (The end of this epoch was at $2^h 28.2^m$.) The subsequent motion was much smaller (max. $2a=2.0$ mm), the amplitude remaining for the next 50^m nearly constant. For the next 30^m the motion was small, being nearly the same as in the 2nd stage of the preliminary tremor.

W_2 . The W_2 motion began at $3^h 36.9^m$, when the motion became larger again and remained active for the next 27^m , comprising a number of max. groups. The greatest $2a$ was 2.6 mm.

69. Bidston (Liverpool). England. Liverpool Observatory. (Director. W. E. Plummer.) Time of Commencement= $1^h 0^m 36^s$. Total Duration= 4^h .

The motion during the successive epochs was as follows:—

- (i) For 3.1^m : small, but distinct.
- (ii) „ 4.6^m : larger, max. $2a=1.0$ mm.
- (iii) „ 2.9^m : max. $2a=2.0$ mm, occurred at the commencement.
- (iv) „ 6.0^m : there were 5 small maximum groups, the 3rd and 4th having the max. $2a$ of 3.0 mm. $T=21.2$ sec.
- (v) „ 6.7^m : the motion gradually reached a max. $2a=4.5$ mm, there being, however, among it some alternations of max. and min. $T=19.2$ sec.

So far the motion lasted 23.3^m and may be regarded as

roughly corresponding to the 1st and 2nd preliminary tremors and the 1st and 2nd phases of the principal portion.

- (vi) For 3.7^m : there was a single group, the motion gradually reaching a max. $2a=12.6$ mm, and again gradually diminishing to a minimum. This epoch, which commenced at $1^h 23^m 54^s$, probably corresponds to the 3rd phase of the principal portion, the maximum motion having occurred at $1^h 28^m 54^s$. $T=18.3$ sec.
- (vii) For 3.6^m : there were 4 max. groups, of which the 3rd had the max. $2a$ of 11.4 mm. $T=19.4$ sec.
- (viii) For 3.3^m : there was a single group, gradually reaching the absolute max. $2a=20.0$ mm, at $1^h 29^m 48^s$.
- (ix) For 30.8^m : the motion remained on the whole constant (max. $2a=11.0$ mm), there being a series of max. groups. At the middle of this epoch, T was 18.8 sec.
- (x) For 13.4^m : there was not much alternation of max. and min. groups, the $2a$ diminishing to 1.9 mm; $T=18.2$ sec.

The subsequent motion was much smaller, and may be taken as the *end portion*:— $T=18.2$ sec. Among a number of max. groups, there were two well defined ones, as follows:—

- (1) $2a=2.0$ mm, between $2^h 22^m 0^s$ and $2^h 35^m 12^s$;
- (2) $2a=1.6$ „ „ „ „ $2^h 39^m 36^s$ and $2^h 49^m 36^s$.

W₁. The W_1 motion appeared at $3^h 28^m 58^s$, there being, for the next $13^m 18^s$, a continuous max. group, till $3^h 44^m 6^s$. The max. $2a$ of 4.2 mm occurred at $3^h 37^m 48^s$; $T=17.5$ sec. The subsequent motion was smaller. The period T was 21.2 sec. in the epoch corresponding to the earlier part of the 2nd preliminary tremor, and 17.5 sec. in what may correspond to the 3rd phase of the principal portion of the W_1 motion. The 6 other values of the period given above varied between 18.2 and 19.4 sec.,

the average being 18.7 sec., which evidently represents the oscillation period of the pendulum.

70. *Edinburgh*, Scotland. Royal Observatory. (Director, Dr. R. Copeland. Observer, Thomas Heath.)

Time of Commencement = $1^h 0^m 0^s$. Total Duration = $3^h 43^m$.

The Edinburgh diagram is very much similar, almost group for group, to that obtained at Kew. The instruments at these two stations had probably nearly equal oscillation periods. The movements in the successive stages of motion were as follows:—

- (i) For 6.5^m : the motion was very small.
- (ii) „ 6.0^m : the motion rapidly reached a max. $2a$ of 4.0 mm, at 2.0^m from the commencement, thence being gradually reduced to a minimum.
- (iii) „ 5.2^m : a max. $2a$ of 5.5 mm was gradually reached at 3.0^m from the commencement, thence being again reduced to a minimum.
- (iv) „ 5.0^m : there was an ill defined max. group, $2a = 3.5$ mm.

So far the motion altogether lasted 22.7^m and corresponds to the 1st and 2nd preliminary tremor and the 1st and 2nd phases of the principal portion. The following three epochs, (v) to (vii), which began at $1^h 22.^m 6$, and together lasted 9.7^m probably corresponds to the 3rd phase of the principal portion.

- (v) For 2.2^m : there was a single max. group, $2a = 10.0$ mm.
- (vi) „ 2.9^m : there were two max. groups, each having max. $2a$ of 18.0 mm.
- (vii) „ 4.6^m : the motion was most active and consisted of two main groups, the 2nd having max. $2a$ of 32 mm, which occurred at $1^h 31.5^m$.
- (viii) „ 21.0^m : the motion became much smaller (max. $2a = 8.0$ mm),

there being a series of about 11 max. groups, whose average interval was 2.1^m .

- (ix) For 9.5^m : there were 5 max. groups (max. $2a=6.0$ mm), with an average interval of 1.9^m . The 1st 3 groups are nearly amalgamated into one continuous maximum.
- (x) „ 7.3^m : there was a continuous max. group, max. $2a=5.0$ mm.
- (xi) „ 2.0^m : a small max. group, $2a=3.0$ mm.
- (xii) Then followed a max. group, whose max. $2a=6.0$ mm occurred at $2^h 13.4^m$.
- (xiii) The subsequent max. groups were more or less active (max. $2a=2.5$ mm) up to $2^h 39.9^m$.
- (xiv) For 34.3^m : the motion was on the whole constant; max. $2a=1.4$ mm.
- (xv) „ 33.3^m : the motion was smaller, and nearly constant; max. $2a=1.0$ mm.

W_2 . The W_2 motion appeared at $3^h 46.9^m$, forming a max. group for about 13.3^m ; max. $2a=2.0$ mm.

71. *Paisley*, Scotland.

The Coats Observatory. (Superintendent, David Crilley.)

Time of Commencement= $1^h 0.0^m$. Total Duration= $3^h 10^m$.

1st Preliminary Tremor. Duration= 8.3^m . The motion was very small during the first 4.1^m .

The subsequent movements were as follows.

- (i) For 11.3^m : the motion was large; max. $2a=3.7$ mm.
- (ii) „ 4.6^m : the motion was again smaller.
- (iii) „ 13.7^m : the most active part of motion, commencing at $1^h 23.9^m$. The max. group, ($2a=32.5$ mm,) occurred at $1^h 31.2^m$.
- (iv) „ 12.2^m : the motion was smaller, but still active; max. $2a=10$ mm.
- (v) „ 29.6^m : the motion was nearly constant; max. $2a=5.0$ mm.

Thereafter the motion became again smaller, being, however, more or less active till 3^h 18^m.

W_2 . The W_2 motion began at 3^h 48.4^m, there being, during the next 18.5^m, two main groups, 2*a* of the first being 1.8 mm.

72. *San Fernando*, Spain.

Instituto y Observatorio de Marina. (Director, Capitán de Fragata Tomás de Azcárate.)

Time of Commencement = 1^h 2.5^m. Total Duration = 3^h 46^m.

The San Fernando seismogram is much similar to those obtained at Edinburgh and Kew; especially, between the commencement of the 3rd phase of the principal portion and about 2^h 30.7^m, and also in the *end portion*, the San Fernando and Kew diagrams are almost identical group for group.

The motion was very small during the first 9.2^m. Then, at 1^h 12.3^m there took place the first max. group (2*a* = 2.0 mm). What may be regarded as the 3rd phase of the principal portion began at 1^h 27.1^m. The times of occurrence and the 2*a*'s of the successive maximum movements are given in the following list.*

Time.	Max. 2 <i>a</i> .	Time.	Max. 2 <i>a</i> .
1 ^h 16.0 ^m	2.50 ^{mm}	1 ^h 45.5 ^m	5.25 ^{mm}
1 23.0	3.75	1 57.5	6.25
1 26.0	4.25	2 1.5	5.50
1 29.0	8.75	2 6.5	4.25
1 34.0	8.75	2 14.0	4.25
1 36.0	6.75	2 23.0	2.25
1 39.0	7.25	3 38.5	2.00
1 41.0	6.25	3 46.0	1.50
1 42.0	6.25		

* This list was kindly furnished by Cap. Azcárate.

W. The W_2 motion began at $3^h 30.7^m$, lasting for about 20^m . The max. $2a$ was 3.7 mm.

73. *New Zealand Records.*

The seismograms obtained at Wellington and Christchurch are reproduced in Pl. XXI, the *Publications*, No. 23. Some of the more prominent maxima identified in the two records are marked by the letters $a, b, c, \dots x, y, z$.

74. *Wellington, New Zealand.* (Observer, G. Hogben, M. A.)

Time of Commencement = $1^h 9.8^m$. Total Duration = $3^h 40^m$.

For the first 10.0^m , the motion was extremely small. At $1^h 17.5^m$ there took place a very slight maximum, the motion for the next 2.2^m being again small. Then took place the first well defined maximum motion. This, marked a , and the subsequent maxima, marked $b, c, \dots y, z$, were as follows:—

$a.$	$\dots 1^h 19.8^m,$	$2a = 1.2$ mm
$b.$	$1\ 25.6,$	$2a = 2.1$
$c.$	$1\ 26.9,$	$2a = 1.1$
$d.$	$1\ 29.9,$	$2a = 1.8$

The epoch between the commencement and d , whose duration was 20.1^m , probably corresponds to the 1st preliminary tremor. For the next 13.6^m , the motion consisted of a series of small maximum groups, the greatest being the following:—

$e.$	$\dots 1^h 41.8^m,$	$2a = 3.0$ mm
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Judging from the Christchurch diagram, the subsequent portion seems to be made up of long period vibrations, and the next 17.1^m probably corresponds to the 1st and 2nd phases of the principal portion. For the first 8.9^m of this portion the motion was small, the max. $2a$ being 5.0 mm. For the remain-

ing 8.2^m , the motion was much greater, the two last maxima being as follows :—

$$\left\{ \begin{array}{ll} f. \dots 1^h 57.6^m, & 2a=13.6 \text{ mm} \\ g. & 1 \ 59.9, \ 2a=11.6 \text{ „} \end{array} \right.$$

For the next 14.8^m , which probably corresponds to the 3rd phase of the principal portion, the motion consisted essentially of 2 groups of maxima, which lasted 5.6 and 7.0^m respectively, the two being separated by a minimum whose duration was 2.2^m . The 1st group consisted of 3 sub-maxima, whose first and 3rd ones were as follows :—

$$\left\{ \begin{array}{ll} h. \dots 2^h 2.2^m, & 2a=23.0 \text{ mm} \\ i. & 2 \ 4.9, \ 2a=21.0 \text{ „} \end{array} \right.$$

The 2nd group also consisted of 3 maxima, whose first two were as follows :—

$$\left\{ \begin{array}{ll} j. \dots 2^h 10.1^m, & 2a=21.0 \text{ mm} \\ k. & 2 \ 11.9, \ 2a=26.0 \text{ „} \end{array} \right.$$

Thereafter the motion became much smaller and consisted, for the next 13.2^m , of 7 max. groups, the first of which has a max. $2a$ of 6.8 mm : the times of occurrence of the maximum movements being as follows :—

$$\left\{ \begin{array}{ll} l. \dots 2^h 16.8^m & p. \dots 2^h 24.5^m. \\ m. & 2 \ 18.8 \\ n. & 2 \ 20.5 \\ o. & 2 \ 21.5 \end{array} \right. \quad \left\{ \begin{array}{ll} q. & 2 \ 26.5 \\ r. & 2 \ 27.3 \end{array} \right.$$

W_2 . The W_2 motion appeared at $2^h 29.3^m$ and continued for 15.4^m , there being two well defined max. groups, as follows :—

$$\left\{ \begin{array}{ll} s. \dots 2^h 29.3^m, & 2a=5.0 \text{ mm;} \\ t. & 2 \ 34.8, \ 2a=2.0 \text{ „} \end{array} \right.$$

For the next 29.5^m , the motion consisted of a series of detached maxima (greatest $2a=2.4$ mm), some of which occurred as follows :—

$$\left\{ \begin{array}{ll} u \dots 2^h 54.1^m & w \dots 3^h 1.9^m \\ v. \quad 2 \ 56.1 & x. \quad 3 \ 12.6 \end{array} \right.$$

For the next 14.0^m , the motion was small.

„ „ 11.3^m , there was a series of max. groups, of which the greatest was the following :—

$$y \dots 3^h 35.7^m, \quad 2a = 2.0 \text{ mm.}$$

For the next 7.5^m , the motion was small.

„ „ 10.0^m , there was a max. group :—

$$z \dots 3^h 50.0^m, \quad 2a = 1.2 \text{ mm.}$$

Thereafter the motion became much smaller. At $4^h 36.6^m$, however, there appeared a slight but distinct group, consisting of 2 maxima: $2a = 0.7 \text{ mm.}$ These lasted about 6^m , the subsequent motion being very small and doubtful.

75. Christchurch, New Zealand. Magnetic Observatory.
(Observer, Henry F. Skey, B. Sc.)

Time of Commencement = $1^h 10.0^m$. Total Duration = $3\frac{1}{2}^h$

The diagram, which is very distinct, is on the whole similar to that obtained at Wellington. The successive maxima were as follows.

Maximum.	Time of Occurrence.	$2a$.	Maximum.	Time of Occurrence.	$2a$.
<i>a</i>	$1^h 17.5^m$	1.7^{mm}	<i>g</i>	$2^h 5.5^m$	9.6^{mm}
<i>b</i>	$1 \ 23.6$	2.0	<i>h</i>	$2 \ 8.0$	17.0
<i>c</i>	$1 \ 25.9$	3.9	<i>i</i>	$2 \ 13.0$	14.2
<i>d</i>	$1 \ 30.1$	5.0	<i>j</i>	$2 \ 17.4$	9.5
<i>e</i>	$1 \ 44.5$	3.0	<i>k</i>	$2 \ 20.0$	16.4
<i>f</i>	$2 \ 2.4$	14.0	<i>l</i>	$2 \ 24.2$	9.0

Maximum.	Time of Occurrence.	2a.	Maximum.	Time of Occurrence.	2a.
<i>m</i>	^h 2 ^m 26.3	^{mm} 10.0	<i>l</i>	^h 2 ^m 45.7	^{mm} 2.9
<i>n</i>	2 28.9	5.4	<i>u</i>	3 4.4	1.3
<i>o</i>	2 30.4	6.3	<i>v</i>	3 8.3	3.9
<i>p</i>	2 32.6	5.0	<i>w</i>	3 15.1	2.1
<i>q</i>	2 34.7	2.1	<i>x</i>	3 22.2	1.7
<i>r</i>	2 35.8	3.2	<i>y</i>	3 53.1	1.2
<i>s</i>	2 38.8	6.1	<i>z</i>	4 11.2	0.9

Notes to the above table :—.

Between the commencement of the earthquake and (*a*), the motion was extremely small.

Between (*a*) and (*d*), both inclusive, there were 6 maximum groups, very nearly equidistant, the average interval being 2.5".

For some interval after (*e*), $T=28.0$ sec.

Other measurements of the period were as follows :—

$$\left\{ \begin{array}{l} \text{Between } (f) \text{ and } (h) : T=18.0 \text{ sec.} \\ \text{,, } (h) \text{ and } (k) : \text{,,}=16.3 \text{ ,,} \\ (s) \text{ : ,,}=15.5 \text{ ,,} \end{array} \right.$$

The last three determinations give the average value of 16.6 sec., which must be the oscillation period of the pendulum. The period of 28 sec., for (*e*), was probably that of the earthquake motion at that particular epoch.

76. Mauritius. Royal Alfred Observatory. (Director, T. F. Claxton, F.R.A.S. Assistant Director, A. Walter.)

The seismograph had two components, EW and NS, the sensibilities to tilting being as follows :—

$$\begin{cases} \text{NS Component: } 1 \text{ mm} = 0^{\circ}29; \\ \text{EW } \quad \quad \quad : 1 \text{ mm} = 0.26 \end{cases}$$

Time of Commencement = $0^{\text{h}} 58^{\text{m}} 54^{\text{s}}$. Total Duration = 2^{h} .

1st Preliminary Tremor. The motion was very small, the duration being as follows:—

$$\begin{cases} \text{NS} \dots\dots 8.0^{\text{m}}; \text{EW} \dots\dots 8.3^{\text{m}}. \\ \text{Mean duration} = 8^{\text{m}} 9^{\text{s}}. \end{cases}$$

2nd Preliminary Tremor. The duration was as follows:—

$$\begin{cases} \text{NS} \dots\dots 9.4^{\text{m}}; \text{EW} \dots\dots 8.6^{\text{m}}. \\ \text{Mean duration} = 8^{\text{m}} 59^{\text{s}}. \end{cases}$$

Then there took place, in the NS component, a displacement of the pendulum towards the north; the EW pendulum remained in position. The subsequent record is very obscure; the motion becoming small after $5^{\text{h}} 52^{\text{m}}$.

77. Cape of Good Hope. (Pl. XXI, the *Publications*, No. 23.)

Royal Observatory (Director, Sir David Gill, K. C. B., F. R. S.)

Time of Commencement = $1^{\text{h}} 2.5^{\text{m}}$. Total Duration = $2^{\text{h}} 6^{\text{m}}$.

The commencement was not quite distinct.

1st Preliminary Tremor. Duration = $9^{\text{m}} 57^{\text{s}}$.

2nd Preliminary Tremor began with a max. group ($2 = 4.0$ mm), and remained for the next 23.3^{m} smaller than 1.5 mm. Then, at $1^{\text{h}} 36.2^{\text{m}}$, the motion became most active (max. $2a = 5.2$ mm), continuing so for 21.8^{m} .

Thereafter the motion became smaller, remaining nearly constant for the next 24.3^{m} (max. $2a = 2.0$ mm). The subsequent motion gradually diminished; very slight but distinct movement being indicated for further 30^{m} .

W. What may correspond to the W_2 motion, consisting of a very slight maximum, appeared at $3^{\text{h}} 8.3^{\text{m}}$.

78. Toronto, Ontario, Canada. (Pl. XXII, the *Publications*, No. 23.) Met. Observatory (Director, R. F. Stupart, F. R. S. C).

Time of Commencement = $1^h 6.6^m$. Total duration = $3^h 33^m$.

The diagram is not very distinct.

1st Preliminary Tremor. During the first 7.6^m , the motion was very slight and doubtful. The first maximum group occurred at $1^h 14.2^m$, the $2a$ being 1.2 mm, and lasting for 3.9^m .

For the next 8.8^m , the motion was very small.

„ „ 22.7^m , „ „ was larger ($2a = 1.8$ mm).

Then, at $1^h 49.7^m$, there began the most active portion, which lasted 20.4^m ; max. $2a = 6.6$ mm.

For the next 38.5^m , the motion was smaller but more or less active, thence gradually decreasing.

79. Victoria, B.C., Canada. (Pl. XXII, the *Publications*, No. 23.) Meteorological Observatory (Superintendent, E. Baynes Reid).

Time of Commencement = $1^h 6.8^m$. Total duration = $3^h 33^m$.

For the first 37.0^m , the motion was small:— $2a = 2.0$ mm.

For the next 11.3^m , the motion was most active:— $2a = 12.4$ mm.

For the next 22.6^m , the motion remained nearly constant:— $2a = 2.8$ mm.

The motion then gradually diminished.

The diagrams at Toronto and Victoria are similar in the earlier part of the motion.

80. Baltimore, Md., U.S.A. (Prof. Harry Fielding Reid.)

Time of Commencement = $1^h 10^m 30^s$. Total Duration = $3^h 40^m$.

The commencement is very indistinct, the indication becoming definite first at $1^h 15^m 48^s$.

The total duration of the 1st and 2nd preliminary tremors $= 42^m 36^s$ (?) ; $2a = 2.0$ mm.

The most active part began at $1^h 53^m 6^s$ and remained nearly constant for $20^m 24^s$, there being 6 maximum groups, the largest of which ($2a = 6.0$ mm) occurred at $2^h 10^m$.

The subsequent motion was much smaller (max. $2a = 2.5$ mm) and remained on the whole nearly constant for the next $15^m 30^s$; there being 4 max. groups occurring at an average interval of $5^m 10^s$. These 4 groups comprised altogether 64 complete (pendulum) oscillations, giving an average period of 15.2 sec. Thence the motion became again much smaller.

The duration of the principal portion was about 49^m .

The end of motion was at about $4^h 50^m$.

W_2 . What may correspond to the W_2 motion occurred at about $3^h 13^m 30^s$; $2a = 0.8$ mm.

81. *Calcutta*, India. (Pl. XX, the *Publications*, No. 23).

Alipore Observatory. (Director, G. W. K  chler, Assistant Meteorological Reporter).

The motion began very gradually, the duration of the preliminary tremor being about $3^m 9^s$. For the next $15^m 18^s$, the motion was very active and the boom end swang through the whole width of the photographic paper. For the next $13^m 24^s$, the motion was still active, but consisted in 5 max. groups. Then the motion gradually diminished till about $8^h 38^m$ (Calcutta time). Thereafter it remained very small.

W_2 began at $9^h 37^m$ (Calcutta Time), or at $2^h 56^m$ after the commencement of the earthquake. For the 1st 13^m , the motion was small and doubtful. For the next $16^m 30^s$, it was well defined, the last group having a max. $2a$ of 1.8 mm. After 4^m ,

during which the motion was small, there took place a small max. group ($2a=1.0$ mm), lasting 4.6^m . This latter may correspond to W_3 .

82. Kodaikānal, Madras, India.

Solar Physics Observatory. (Director, C. Michie Smith.)

The instrument had evidently a great friction, and the record is not satisfactory.

Commencement= $6^h 16.3^m$ (Madras Time), or $0^h 55.6^m$ (G.M.T.)

Total Duration= $3^h 36^m$.

The *1st Preliminary Tremor* lasted $3^m 55^s$, the max. $2a$ being 1.8 mm. For the next $2^m 19^s$ there were two max. groups, the first having the max. $2a$ of 22.6 mm. Then the index strack sideways and the record was not given till $8^h 13^m$ (Madras time), when the pointer was brought back by hand and put into the working condition again. The motion was distinctly shown till $8^h 33.2^m$ (Madras time), the max. $2a$ during this interval being about 1 mm. Thereafter the motion became very slight, and for the next 58.5^m , there was no very great variation, showing a series of very small max. groups.

A small maximum group, similar in form to that in the Liverpool and Edinburgh diagrams, occurred at $8^h 57.7^m$ (Madras time). This may correspond to W_2 , but the record is doubtful and the above may be a time signal.

83. Colaba, Bombay. (Pl. XX, the *Publications*, No. 23.)

Government Observatory. (Director, N.A.F. Moos.)

Commencement= $0^h 52.9^m$. Total Duration= $4^h 19.6^m$.

The diagram is on the whole similar to the Alipore one.

After the preliminary tremor, which lasted $3^m 31^s$, the motion became

suddenly large and continued very active for 8^m 42^s. During the next 9^m 42^s, it consisted of a number of separate maximum groups. Thereafter the motion gradually diminished.

The identification of W_2 and W_3 is doubtful.

84. Honolulu, T.H.* (Observer, S.A. Deel. Compiler, A.E. Burbank.)

Commencement.....	1 ^h 04. ^m 6
2nd Group	1 08. 7
Long Waves.....	1 15. 0
Maximum	{ 1 35. 2 (2.5 mm)
	{ 1 47. 2 (4.5 „)
	{ 1 55. 5 (8.2 „)
End	5 20. 0

Chapter IV. Velocity of Propagation of the 1st Preliminary Tremor.

85. Places situated approximately on Same Great Circles of the Earth passing through the Origin of the Earthquake.

The origin of the earthquake under consideration is situated among the great Himalayan mountain range, in the middle of the extensive continent of Asia. A question which naturally presents itself in connection with the transit velocity is whether or not the latter differed along the various routs of radial propagation. With a view of finding out such a relation, if possible, I have divided the different observing stations into a number of groups, as follows.

Group 1. Tacubaya, Toronto, Victoria, B.C., Colaba, (Bombay),

* Reproduced from Professor Milne's Circular, No. 13.

Kodaikanal (Madras). The great circle connecting Tacubaya with the earthquake origin passes very nearly through the North Pole; the seismic waves being propagated through the *flat regions* of Siberia and Canada and the depressed tract forming the Arctic basin. The azimuth of Tacubaya with respect to the origin, or the direction of the above mentioned great circle at the latter, is N 4° 36' W.

Toronto and Victoria, B.C., are situated slightly out of the same circle. Colaba (Bombay) and Kodaikanal (Madras) lie nearly on the southern prolongation of the meridian through the origin.

Group 2. Great Britain, North Germany, Batavia. Great Britain and North Germany lie approximately on a great circle passing through the origin, the seismic waves reaching these places after traversing through the *flat grounds* of the Transcaspian and South Russian districts. The stations belonging to this group are as follows.

Great Britain :—Kew, Edinburgh, Birmingham, Shide, Liverpool, Paisley.

North Germany :—Hamburg, Potsdam, Leipzig, Göttingen, Jena. Batavia lies nearly on the southern prolongation of the same great circle.

Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington (New Zealand); Rio de Janeiro; Ponta Delgada (Azores); Taschkent, Tiflis. South Austro-Hungary and North Italy lie nearly on the same great circle through the origin, which coincides with the Caucasus Range; the paths of the earthquake propagation being in this case through *mountainous regions*. Azores, Tiflis, and Taschkent are also not much away from the same circle, while Calcutta, Taungoo (Burma), New Zealand, and Rio de Janeiro are roughly on the south-eastern prolongation of the latter.

Group 4. Taschkent, Krakau, Strassburg, Calcutta.

Group 5. Taschkent, Jurjew (Dorpat), Upsala; Porto Rico; Batavia. The great circles on which the stations of these two groups are situated are not far from those for the 2nd and 3rd groups.

Group 6. Japan. The seismic waves reached Japan by paths across plateau and continent, the great circle connecting the origin with Tokyo passing through Tibet, the valley of the Hoang Ho, southern extremity of Korea, and the western part of the Main Island of Japan. The stations of this group are:—Tokyo, Mizusawa, Kobe, Osaka, and Taihoku.

Group 7. Tiflis; Belgrade; Ickia, Messina; Querce, Ximniano, Quarto=Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo; Wellington, Christchurch (New Zealand). All these places are situated approximately on one and the same great circle; the first 9 being towards WNW, and the remaining 4 towards ESE, of the earthquake origin.

Group 8. Washington, Cheltenham, Toronto, Tiflis; Kodai-kanal, Batavia. All these places are approximately on one and the same great circle through the origin, the first 4 being to the NNW, and the remaining 2 to the SSE, of the latter.

Group 9. Honolulu (Hawaii), Irkutsk.

Group 10. Permea, Bairut (Asia Minor).

Single Stations. Those places which do not make groups lying on a great circle through the origin are as follows:—Manila, Mauritius, Cape Town, Baltimore.

86. Methods of Calculating the Velocities of Earthquake Propagation.* There are two distinct methods of the velocity calculation, as follows:—

(A) “Direct Method,” in which the transit velocity is obtained

* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 1.

by dividing the epicentral distance of a station by the difference between the times of occurrence of a particular phase of motion at the latter and the origin of disturbance. Thus, if x' be the epicentral distance of a place, and t' and t_0 be respectively the times of occurrence at the latter and the origin, we have :—

$$\text{Velocity} = \frac{x'}{t' - t_0}.$$

(B) “Difference Method,” in which the velocity is obtained by dividing the difference of the epicentral distances of any two stations by the difference of the times of occurrence of a given phase of motion at these stations. Thus, if x' and t' have the same meaning as before and if x'' and t'' be the corresponding quantities at a second place, we have :—

$$\text{Velocity} = \frac{x' - x''}{t' - t''} = \frac{\partial x}{\partial t}.$$

The “difference method” gives always a higher value of the velocity than the “direct method”; the discrepancy, which becomes smaller with the increase of the epicentral distance, being markedly shown up to the distance of about 40°.

In the “difference method,” we have no need of ascertaining the time of occurrence at the origin of disturbance; the inaccuracy about the position of the epicentre being also avoided in a great measure, provided those stations which are taken for combination lie on one and the same great circle passing through the epicentre, on one side of which they are all situated.

The velocities corresponding to the commencement of the different phases of the earthquake motion will be denoted in subsequent §§ by the same symbols as in my former papers, namely, as follows :—

v_1 Velocity of the 1st preliminary tremor;
 v_2 “ 2nd “ “ ;

v_3	Velocity of the 1st Phase, Principal Portion;			
v_4	"	2nd	"	;
v_5	"	3rd	"	;
v_6	"	4th	"	;
v_7	"	5th	"	;
v_8	"	End Portion (8th Section).		

In the velocity calculations, the epicentral distance (x) has been taken to denote the *arcual* length between the earthquake origin and a given station.

I give next the values of the transit velocity v_1 , for the different groups of stations, deduced according both to the "direct method" and the "difference method"; all the necessary data being contained in Table I. For the "direct method" calculation, the time of earthquake occurrence at the epicentre has been assumed to be $t_0=0^h49^m48^s$ G.M.T.

87. Group 1. Tacubaya; Toronto; Victoria, B.C.; Colaba (Bombay); Kodaikanal (Madras).

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Tacubaya	128° 47'	1 ^h 11 ^m 25 ^s	21 ^m 37 ^s	11.03 ^{km/sec.}
Toronto, Victoria, B.C.	99 36	1 06 42	16 54	10.91
Colaba	13 28	0 53 08	3 20	7.48
Kodaikanal	21 35	0 55 48	6 00	6.66

The mean transit velocity along the rout approximately *through the North Pole*, deduced from the observations at Tacubaya, Toronto, and Victoria, was, for $x=114^\circ 12'$, about 10.97 km per sec. The time of commencement given by the Kodaikanal register seems to be somewhat too late.

v_1 calculated by "Difference Method."*

Combination of Stations.	δx	δt_1	v_1
Tacubaya— $\left\{ \begin{array}{l} \text{Toronto} \\ \text{Victoria} \end{array} \right.$	29° 11'	4 ^m 43 ^s	11.45 ^{km/sec.}
„ — Colaba	115 19	18 17	11.68
$\left\{ \begin{array}{l} \text{Toronto} \\ \text{Victoria} \end{array} \right.$ — „	86 08	13 34	11.76

The values of v_1 here obtained agree well with each other and vary between 11.45 and 11.76 km per sec., giving the average velocity of **11.63** km per sec. This is about 0.7 km greater than the value found by the "direct method," and may be regarded as the velocity of the 1st preliminary tremor when passing through the earth's crust near the *North Pole*.

88. Group 2. Great Britain, North Germany; Batavia.

 v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Great Britain. $\left\{ \begin{array}{l} \text{Shide, Kew, Paisley,} \\ \text{Liverpool, Birmingham,} \\ \text{Edinburgh.} \end{array} \right.$	58° 54'	1 ^h 00 ^m 24 ^s	10 ^m 36 ^s	10.30 ^{km/sec.}
North Germany. $\left\{ \begin{array}{l} \text{Hamburg, Leipzig,} \\ \text{Potsdam, Göttingen,} \\ \text{Jena.} \end{array} \right.$	50 50	0 58 43	8 55	10.56
Batavia.	42 35	0 58 33	8 45	9.01

As remarked below, the time given by the Batavia register seems to be a little too late. The results obtained for the two groups of the British and North German stations are practically

* Kodnikanal excluded.

identical, the mean velocity being **10.36** km per sec., for $x=54^{\circ}45'$. The path of the earthquake propagation was, in these cases, almost entirely across flat regions.

v_1 calculated by "Difference Method."

Station.	δx	δt_1	v_1
Great Britain—North Germany	$8^{\circ} 04'$	$1^m 41^s$	$8.87^{km/sec.}$
„ —Batavia	$16 19$	$1 51$	$17.4 (?)$
N. Germany— „	$8 15$	$0 10$	$91.7 (?)$

From this last table it will be seen that the Batavia time was a little too late.

89. Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington; Rio de Janeiro, Ponta Delgada (Azores), Taschkent, Tiflis. *

v_1 calculated by "Direct Method."*

Station.	x	t_1	$t_1 - t_0$	v_1
South Austro-Hungary.... { Laibach. Triest. Pola.	$49^{\circ} 42'$	$0^h 58^m 47^s$	$8^m 59^s$	$10.24^{km/sec.}$
North Italy..... { Querce. Ximeniano. Quarto-Castello. Padova.	$51 46$	$0 58 51$	$9 03$	10.63
Nicolajew.	$37 20$	$0 58 54$	$9 06$	7.60
Calcutta.	$13 42$	$0 52 00$	$2 12$	11.53

(* Time observation of Rio de Janeiro was not satisfactory, while the time of commencement given by the magnetograph at Taungoo is that corresponding to the beginning of the principal portion. These two places have, therefore, been excluded from the calculation of v_1 .)

Station.	x	t_1	$t_1 - t_0$	v_1
New Zealand { Christchurch. Wellington.	115° 24'	1 ^h 09 ^m 54 ^s	20 06	10.63 ^{km/sec}
Ponta Delgada.	79 54	1 01 00	11 12	13.21
Taschkent.	11 20	0 52 24	2 36	8.07
Tiflis.	27 26	0 55 48	6 00	8.47

For large epicentral distances of over 50°, we obtain, by taking the means from the South Austro-Hungary, North Italy, and New Zealand stations, a velocity of **10.50** km per sec. The times given by the Calcutta and Ponta Delgada registers were evidently too early, while that for Nicolajew was a little too late.

The mean value of v_1 deduced from the first two sets of stations, namely, **10.45** km per sec., is the velocity of earthquake propagation partly along the Caucasus Range. This value is, however, practically identical with the transit velocity for the stations of Group 2, for which the path of propagation is situated across the flat grounds.

“Difference Method.” The South Austro-Hungary and North Italy stations are near one another. Taking, therefore, the means from these, we obtain:—

$$x = 50^\circ 44'; \quad t_1 = 0^h 58^m 49^s$$

Combining these values with those for Calcutta, New Zealand, Ponta Delgada, Taschkent, and Tiflis, we obtain:—

Station.	δx	δt_1	v_1 “Difference Method.”
Calcutta.	37° 02'	6 ^m 49 ^s	10.06 ^{km/sec.}
{ Christchurch. Wellington.	64 40	11 06	10.80

Station.	δx	δt_1	v_1 (“Difference Method”)
Nicolajew.	13° 24'	^m — ^s 05	^{km/sec.} (?)
Ponta Delgada.	29 10	2 12	24.73
Taschkent.	39 24	6 24	11.37
Tiflis.	23 18	3 00	14.30

Here again we see that the Calcutta time was slightly too early, while the Ponta Delgada time was probably more than 2 minutes too early. The results relating to these two stations are, therefore, to be excluded from the discussion of the velocity v_1 . We have further:—

Combination of Stations.	δx	δt_1	v_1
New Zealand-Taschkent.	104° 04'	^m 17 ^s 30	^{km/sec.} 11.01
„ -Tiflis.	87 57	14 06	11.55
Tiflis -Taschkent.	16 06	3 24	8.77

Excepting the last combination, in which the distance (x) of each station was small, we obtain the following mean value:—
 $v_1 = 11.81$ km per sec.

The exceptionally high velocity of 14.30 km per sec., obtained by combining Tiflis with Austro-Hungarian and Italian stations, can not otherwise be explained than by supposing that the transit velocity between Tiflis and the origin of disturbance was comparatively low.

90. Group 4. Taschkent, Krakau, Strassburg ; Calcutta, v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Taschkent.	11° 20'	0 ^h 52 ^m 24 ^s	2 ^m 36 ^s	8.07 ^{km/sec.}
Krakau.	45 30	0 58 12	8 24	10.03
Strassburg.	53 31	0 58 26	8 38	11.48
Calcutta.	13 42	0 52 00	2 12	11.53

 v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
Strassburg-Krakau.	8° 01'	0 ^m 14 ^s	63.6 (?) ^{km/sec.}
„ -Taschkent.	42 11	6 02	12.95
„ -Calcutta.	39 49	6 26	11.46
Krakau-Taschkent.	34 10	5 48	10.91
„ -Calcutta.	31 48	6 12	9.50
Calcutta-Taschkent.	2 22	(-0 24)	(?)

The two above tables show that both the Strassburg and Calcutta times were somewhat too early. Rejecting, therefore, the results relating to these two places, we obtain :—

Taschkent..... v_1 (Direct Method) = 8.07 km/sec.
 Krakau..... v_1 „ = 10.03 „
 Krakau-Taschkent... v_1 (Difference Method) = 10.91 „

91. Group 5. Porto Rico, Batavia, Taschkent, Upsala. v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Taschkent.	11° 20'	0 ^h 52 ^m 24 ^s	2 ^m 35 ^s	8.07 ^{km/sec.}
Batavia.	42 35	0 58 33	8 45	9.01
Jurjew.	42 49	0 57 52	8 04	9.87
Upsala.	47 41	0 58 22	8 34	10.31
Porto Rico.	118 25	1 10 25	20 37	10.64

 v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
(i) Porto Rico—Upsala.	70° 44'	12 ^m 03 ^s	10.87 ^{mk/sec.}
(ii) " — { Jurjew. Batavia.	75 43	11 52	11.82
(iii) " — Taschkent.	107 05	18 01	11.01
(iv) Upsala — { Jurjew Batavia.	4 59	00 09	61.5 (?)
(v) " — Taschkent.	36 21	5 58	11.28
(vi) { Jurjew } { Batavia } — "	31 22	5 49	9.99

Excluding (iv), we get the following mean values:—

$$\delta x = 84^\circ 31', \dots \dots \dots v_1 = 11.23 \text{ km/sec.}$$

$$\delta x = 33 \ 52, \dots \dots \dots v_1 = 10.64 \quad "$$

92. Group 6. Japan:—Tokyo, Mizusawa; Kobe, Osaka, Tadotsu; Taihoku. The time of commencement at Tadotsu is slightly doubtful, owing to some indistinctness in the time-marking, and is, therefore, excluded in the following calculation of v_1 .

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Tokyo, Mizusawa.	51° 33'	0 ^h 59 ^m 11 ^s	9 ^m 23 ^s	10.17 ^{km/sec.}
Osaka, Kobe.	48 11	0 58 39	8 51	10.08
Taihoku.	39 27	0 57 19	7 31	9.72

Taking together the 4 stations of Tokyo, Mizusawa, Osaka, and Kobe, we obtain :— $v_1 = 10.13$ km/sec.

 v_1 calculated by "Difference Method."

Combination of Stations.	Δx	Δt_1	v_1
Tokyo, Mizusawa—Osaka, Kobe.	3° 22'	0 ^m 32 ^s	11.69 ^{km/sec.}
„ — Taihoku.	12 06	1 52	12.00
Osaka, Kobe — „	8 44	1 20	12.11

The average value of v_1 deduced from the above 3 combinations is **11.93** km per sec,

93. Group 7. Tiflis; Belgrade; Ischia, Messina; Querce, Ximentiano, Quarto-Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo*; Wellington, Christchurch (New Zealand).

 v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Tiflis.	27° 26'	0 ^h 55 ^m 48 ^s	6 ^m 00 ^s	8.47 ^{km/sec.}
Belgrade.	45 29	0 57 47	7 59	10.55

Station.	x	t_1	$t_1 - t_0$	v_1
Ischia, Messina.	50° 08'	^h 0 ^m 58 ^s 58	^m 9 ^s 10	^{km/sec.} 10.13
{ Querce, Ximeniano, Quarto- Castello, Rocca di papa. . . .	51 45	0 58 55	9 07	10.61
San Fernando.	66 47	1 02 30	12 42	9.74
Wellington, Christchurch.	115 24	1 09 54	20 06	10.63

The 7 stations of Belgrade, Ischia, Messina, Querce, Ximeniano, Quarto-Castello, and Rocca di papa, give the following means :—
 $x = 50^\circ 27'$; $v = 10.46$ km/sec.

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
{ Wellington, Christchurch - San Fernando.	48° 37'	^m 7 ^s 24	^{km/sec.} 12.16
" - 6 Italian Stations.	64 11	10 58	10.84
" - Belgrade.	69 55	12 07	10.69
" - Tiflis.	87 58	14 06	11.55
San Fernando - 6 Italian Stations.	15 34	3 34	8.09
" - Belgrade.	21 18	4 43	8.36
" - Tiflis.	39 21	6 42	10.87
6 Italian Stations - Belgrade.	5 44	1 09	9.23
" - Tiflis.	23 47	3 08	14.05
Belgrade - "	18 03	1 59	16.85

From the last table it will be seen that the time of commencement at San Fernando was a little too late, while that at Belgrade was a little too early. Taking together all the results, the mean value of v_1 comes out to be 11.27 km/sec.

* Calcutta and Taungoo are excluded in the calculation of v_1 . See §. 89.

**94. Group 8. Washington, Cheltenham, Toronto, Tiflis ;
Kodaikanal, Batavia.**

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Washington, Cheltenham.	105° 20'	1 ^h 08 ^m 32 ^s	18 ^m 44 ^s	10.41 km/sec.
Toronto.	101 30	1 06 36	16 48	11.18
Tiflis. (See § 89)	—	—	—	8.47
Kodaikanal. („ § 87)	—	—	—	6.70
Batavia. („ § 88)	—	—	—	9.01

Of the above 5 cases, the results relating to Toronto, Kodaikanal, and Batavia, are probably not quite accurate. (See below.)

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
(i) Washington, Cheltenham—Toronto.	3° 50'	1 ^m 56 ^s	3.67 (?) km/sec.
(ii) „ —Tiflis.	77 54	12 44	11.33
(iii) „ —Kodaikanal.	83 45	12 44	12.18
(iv) „ —Batavia.	62 45	9 59	11.64
(v) Toronto —Tiflis.	74 04	10 48	12.69
(vi) „ —Kodaikanal.	79 55	10 48	13.70
(vii) „ —Batavia.	58 55	8 03	13.55
(viii) Tiflis —Kodaikanal.	5 51	0 00	(?)
(ix) Batavia —Tiflis.	15 09	2 45	10.20
(x) „ —Kodaikanal.	21 00	2 45	14.14

Of the above 10 combinations, (i) shows that the Toronto time was a little too early. In the three cases of (v), (vi), and (vii), therefore, the velocity deduced would be a little too high.

Again, (viii) shows that the Kodaikanal time was a little too late. Consequently, the value of the velocity in the three cases of (iii), (vi), and (x), would be too high. Excluding these doubtful cases, 7 in number, we find :—

$$(ii) \quad v_1 = 11.33 \text{ km per sec.}$$

$$(iv) \quad v_1 = 11.64 \quad ,,$$

$$(ix) \quad v_1 = 10.20 \quad ,,$$

Of these three cases, the last, relating to Tiflis and Batavia, is probably not so accurate as the other two; the Batavia time being not quite exact, as remarked in § 88. The mean value of the velocity comes out to be **11.49** km per sec.

95. Group 9. Honolulu (T.H.) and Irkutsk.

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Irkutsk.	28° 28'	0 ^h 55 ^m 44 ^s	5 ^m 56 ^s	km/sec. 8.88
Honolulu.	108 27	1 04 36	14 48	13.57

v_1 calculated by "Difference Method."

Honolulu—Irkutsk :— $\partial x = 79^\circ 59'$; $\partial t_1 = 8^m 52^s$. $v_1 = 16.70$ km/sec.

Judging from the above values of the velocity v_1 , the Honolulu time seems to have been a little too early.

96. Group 10. Formosa, Bairût (Asia Minor).

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Taihoku.	39° 27'	0 ^h 57 ^m 19 ^s	7 ^m 31 ^s	km/sec. 9.72
Bairût.	34 41	0 58 00	8 12	7.83

v_1 calculated by "Difference Method."

Bairût—Taihoku. . . . $\delta x = 4^\circ 46'$; $\delta t_1 = -41$ sec. ; $v_1 = (?)$ km/sec.

The time of commencement at Bairût was evidently a little too late.

97. Single Stations. "Direct Method."

Station.	Epicentral Distance.		$t_1 - t_0$		v_1
Mauritius.	55°	15'	9 ^m	06 ^s	11.24 ^{km/sec.}
Cape Town.	85	46	12	42	12.51
Baltimore.	104	47	20	42	9.37

SUMMARY.

98. Velocity and Nature of Path. According to the velocity calculations by "difference method" given above, the time (t_1) of earthquake occurrence at some of the stations seem to have been slightly inaccurate, as follows :—

(a) t_1 registered at Kodaikanal, Batavia, San Fernando, Baltimore and Bairût was too late ; (b) t_1 registered at Calcutta, Ponta Delgada, Belgrade, Strassburg, Toronto, and Honolulu, was too early. Some of these stations, whose time observation leads to the values of the transit velocity much different from those for the others, have been excluded in the deduction of the average group velocity.

v_1 calculated by "direct method." Comparing together the results for the different groups of stations, we see that there was apparently no general *marked* dependence of v_1 on the nature of the path of the seismic waves ; the most trustworthy values of the mean velocity being as follows :—

Group.	Stations.	Nature of Wave Path.	Mean α .	Mean v_1
1	Tacubaya, Toronto, Victoria, B.C.	Through North Pole.	114° 12'	km/sec. 10.97
2	N. Germany, Great Britain.	Across plane regions.	54° 45'	10.36
3	S. Austro-Hungary and N. Italy.	Along mountain ranges.	50° 44'	10.41
4	New Zealand.		115° 24'	10.63
5	Jurjew, Upsala.		45° 15'	10.09
6	Japan.	Through Tibet and China.	49° 52'	10.13
7	Central and S. Italy.		51° 13'	10.45
8	Washington, Cheltenham.		105° 20'	10.41

The stations of Group 1 and New Zealand give high velocities of 10.97 to 10.63 km per sec., the epicentral distances being great and equal to about 115°. It is, however, remarkable that the velocities for Group 2 (mean $\alpha=54^\circ 45'$) and Group 3 (mean $\alpha=50^\circ 44'$) were practically identical, namely, 10.36 and 10.44 km per sec., although the nature of the regions, through which the seismic waves were propagated, differed widely in the two cases, being respectively across plane grounds and along mountain ranges. The path of the waves for Group 1 stations, which approximately passed through the North Pole, is laid for the greater part across flat grounds.

The 4 Japanese stations of Tokyo, Mizusawa, Osaka, and Kobe (Group 6) give a velocity of 10.13 km per sec., which is about 0.27 km less than those of Group 2 and Group 3 stations. This difference *may* be due to the fact that the seismic waves passed, before reaching Japan, through China and the plateau of Tibet; a natural supposition in this connection being that the propagation velocity would be greater in suboceanic or depressed regions, than in plateau or elevated grounds, on account of the difference of rigidity and elasticity of the material

composing the different portions of the earth's surface.

Taking the average from the different groups of stations given in the preceding table, we find :—

for $\alpha=45^{\circ}$ to 115° ; . . . $v_1=10.44$ km per sec.

99. v_1 calculated by “Difference Method.”

The following table gives the mean values of the transit velocity v_1 for the different groups of stations.

Group.	Stations.	Limits of α .	Mean v_1
1	Tacubaya, Toronto, Victoria, B.C., Colaba.	13° 28' 128° 47'	11.63 ^{km/sec.}
2	Great Britain, North Germany.	50 36 — 58 54	10.34
3	S. Austro-Hungary, N. Italy, Calcutta, Christchurch, Wellington, Tashkent, Tiflis.	13 42 — 115 24	11.81
5	Porto Rico, Upsala, Jurjew, Batavia, Tashkent	11 20 — 118 25	11.23
6	Japan:—Tokyo, Mizusawa, Osaka, Kobe, Taihoku.	39 27 — 51 33	11.93
7	Tiflis, Belgrade, 6 Italian Stations, San Fernando, New Zealand.	27 26 — 115 24	11.27
8	Washington, Cheltenham, Tiflis, Batavia.	27 26 — 105 20	11.49

Taking the average from the seven groups of stations contained in the above table, with the exception of the 2nd, in which the distance difference was too small, we obtain :—

for $\alpha=11^{\circ} 20'$ to $128^{\circ} 47'$; mean $v_1=11.56$ km per sec.

100. Velocity v_1 calculated by “Direct Method,” without reference to the Paths of the Seismic Waves. In the following table, the different stations are arranged simply according to the epicentral distance and conveniently divided into a number of groups, the velocity v_1 having been calculated by “direct method.” Those stations marked with *asterisks* have not been taken in the deduction of the mean values of the velocity,*

* See page 148.

TABLE IX. v_1 calculated by "Direct Method."

Station.	Epicentral Distance = x .	Time of occur- rence of 1st Prel. Tremor = t_1	v_1
Earthquake Origin.	—	^h ^m ^s 0 49 48	— km/sec.
Dehra Dun.	1° 45'	0 50 38	—
Taschkent.	11 20	0 52 24	8.07
Colaba.	13 28	0 53 08	7.48
Calcutta.*	13 42	0 52 00	11.53
<i>Mean.</i>	12 24	0 52 46	7.78
Kodlaikanal *	21 35	0 55 48	6.66
5 Caucasus Stations.†	27 11	0 55 39	8.60
Tiflis.	27 26	0 55 48	8.47
Irkutsk.	28 28	0 55 44	8.88
<i>Mean.</i>	27 57	0 55 46	8.68
Nikolajew.*	37 20	0 58 54	7.60
Taihoku.	39 27	0 57 19	9.72
Bairût.*	34 41	0 58 00	7.83
Batavia.*	42 35	0 58 33	9.01
Jurjew.	42 49	0 57 52	9.87
Manila.	43 34	0 58 25	9.36
Belgrade.	45 29	0 57 47	10.55
Krakau.	45 30	0 58 12	10.03
<i>Mean.</i>	43 22	0 57 55	9.91
Tadotsu.	47 02	0 58 49	9.66
Upsala.	47 41	0 58 22	10.31
Kobe.	48 03	0 58 26	10.30
Osaka.	48 19	0 58 51	9.89

* Not taken in deducing the means.

† Achalkalaki, Derbent, Schemacha, Borshom, Batum.

Station.	Epicentral Distance = x .	Time of occur- rence of 1st Prel. Tremor = t_1	v_1 km/sec.
Lailbach.	48° 19'	^h 0 ^m 58 ^s 46	9.98
Messina.	49 46	0 59 00	10.02
Potsdam.	49 48	0 58 46	10.28
Triest.	49 52	5 58 44	10.34
Pola.	49 55	5 58 50	10.23
Leipzig.	50 16	0 58 44	10.42
Ischia.	50 30	0 58 56	10.24
Jena.	50 48	0 58 54	10.20
Rocca di papa.	51 15	0 58 51	10.49
Padua.	51 20	0 58 58	10.34
Tokyo.	51 26	0 59 08	10.20
Hamburg.	51 34	0 58 14	11.32
Mizusawa.	51 39	0 59 08	10.25
Göttingen.	51 45	0 58 55	10.51
Quebec.	51 54	0 59 08	10.30
Ximeniano.	51 55	0 58 33	10.99
Quarto-Castello.	51 56	0 58 49	10.67
Strassburg.	53 31	0 58 26	11.48
<i>Mean.</i>	50 24	0 58 48	10.38
Kew.	58 05	1 00 12	10.33
Edinburgh.	58 48	1 00 00	10.67
Birmingham.	58 49	1 00 35	10.10
Shide.	58 52	1 01 00	9.73
Liverpool.	59 18	1 00 36	10.17
Paisley.	59 30	1 00 00	10.80
<i>Mean.</i>	58 54	1 00 24	10.30
San Fernando.	66 47	1 02 30	9.74

Station.	Epicentral Distance = x	Time of occurrence of 1st Prel. Tremor = t_1	v_1 km/sec.
Ponta Delgada.*	79° 54'	1 ^h 01 ^m 00 ^s	13.21
Cape Town.	85 46	1 02 30	12.51
<i>Mean.</i>	73 07	1 02 30	10.66
Victoria, B.C.	97 42	1 06 48	10.69
Toronto.	101 30	1 06 36	11.19
Baltimore.*	104 47	1 10 30	9.37
Washington, D.C.	105 17	1 08 25	10.47
Cheltenham.	105 22	1 08 39	10.35
Honolulu.*	108 27	1 04 36	13.57
<i>Mean.</i>	103 03	1 07 49	10.61
Christchurch.	115 03	1 10 00	10.54
Wellington.	115 45	1 09 48	10.72
Porto Rico.	118 25	1 10 25	10.64
Tacubaya.	128 39	1 11 25	10.03
<i>Mean.</i>	121 16	1 10 37	10.79

The mean values of the velocity v_1 contained in the above table are as follows.

TABLE X. Mean Values of v_1 calculated by "Direct Method."

Station.	Epicentral Distance = x .	v_1 km/sec.
Taschkent, Colaba	12° 24'	7.78
Tiflis, Irkutsk.	27 57	8.68
Taihoku, Jurjew, Manila, Belgrade, Krakau.	43 22	9.91
(Upsala, Osaka, Kobe, Laibach, Triest, Pola, Messina, Ischia, Jena, Tokyo,		

Stations.	Epicentral Distance = x .	v_1 km/sec.
{ Hamburg, Mizusawa, Rocca di papa, Padova, Querce, Ximeniano, Quarto-Castello, Leipzig, Potsdam, Göttingen, Strassburg.	50° 24'	10.38
{ Kew, Birmingham, Liverpool, Paisley, Edinburgh, Shide	58 54	10.30
San Fernando and Cape Town.	73 07	10.66
{ Toronto, Victoria, B. C., Washington, Cheltenham.	103 03	10.61
{ Christchurch, Wellington, Porto Rico, Tacubaya.	121 16	10.79

As is graphically shown in Fig. 9, the velocity v_1 calculated by "direct method" increased, between the earthquake origin and the epicentral distance of x = about 50°, linearly up to a value of 10.38 km per sec., the velocity at the immediate vicinity of the epicentre being probably some 7 km per sec. For the x greater than 50°, the velocity remained very nearly constant, the maximum being 10.79 km per sec., for x = 121° 16'. According to the above table, the mean velocity (v_1) is as follows:—

$$v_1 = \mathbf{10.52 \text{ km per sec.}} \text{ (for } x = 50^\circ \text{ to } 121^\circ; \text{ mean } x = 76.^\circ)$$

For the sake of comparison, I give in Fig. 9, also the relation between the epicentral distance and the velocity v_1 calculated by "direct method" for the San Francisco earthquake of April 18, 1906.

101. Mean Value of the Velocity v_1 calculated by "Difference Method." The relation between the mean group values of the epicentral distance and the time of occurrence, given in Table IX, is graphically shown in Fig. 7, from which it will be seen





Fig. 7. Indian Earthquake of April 4, 1905. Relation of the Time of Earthquake Occurrence to the Epicentral Distance.

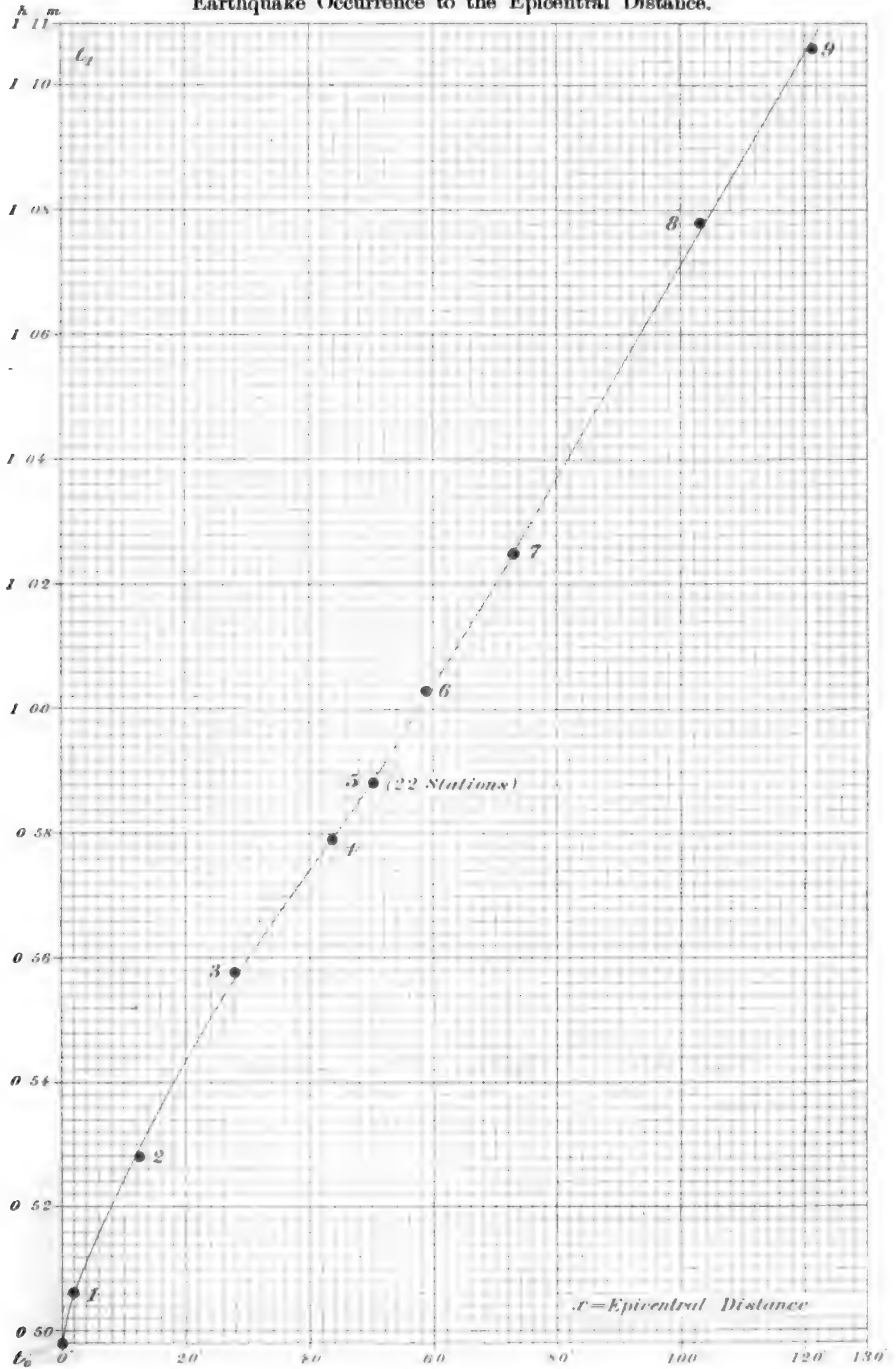
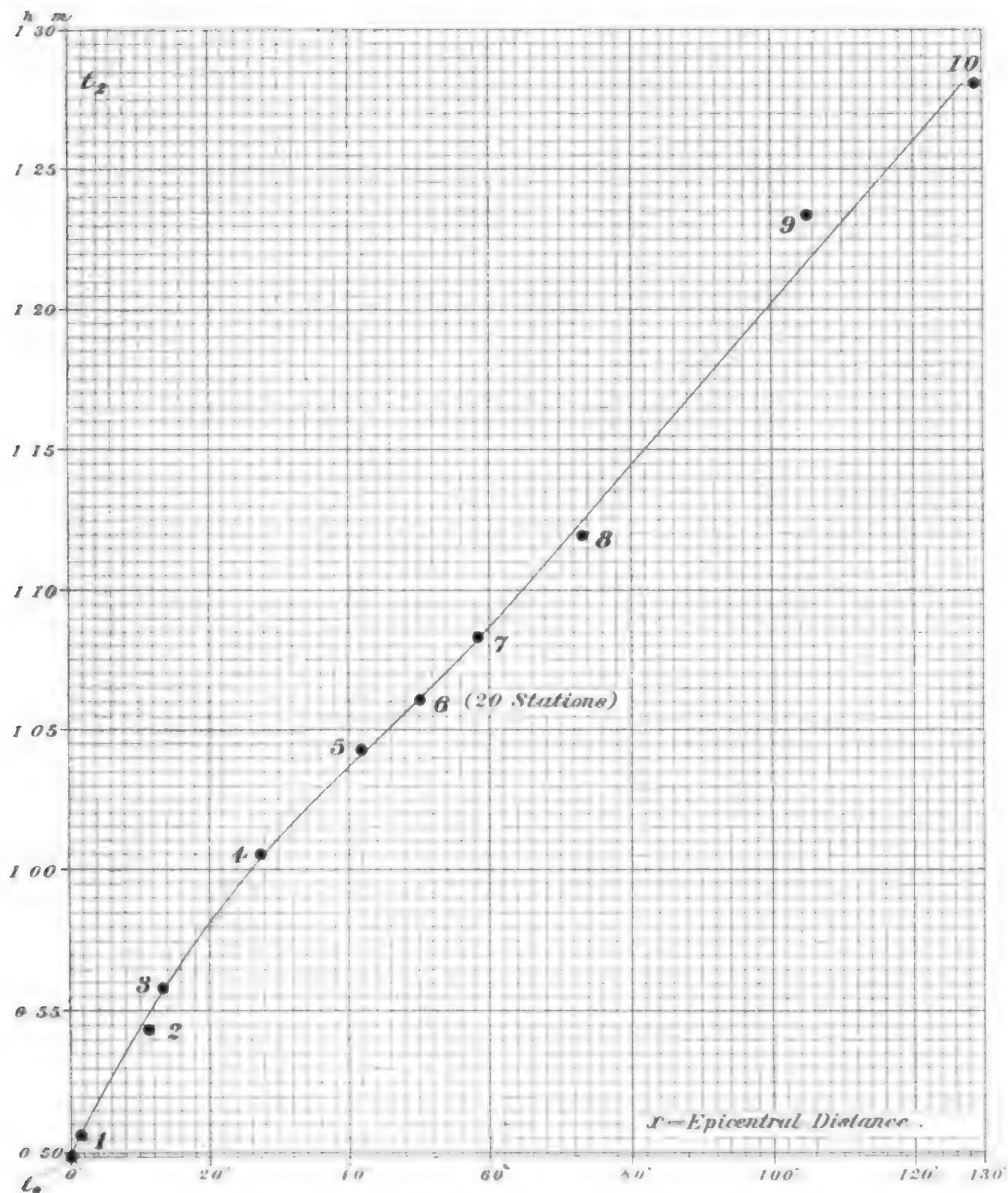
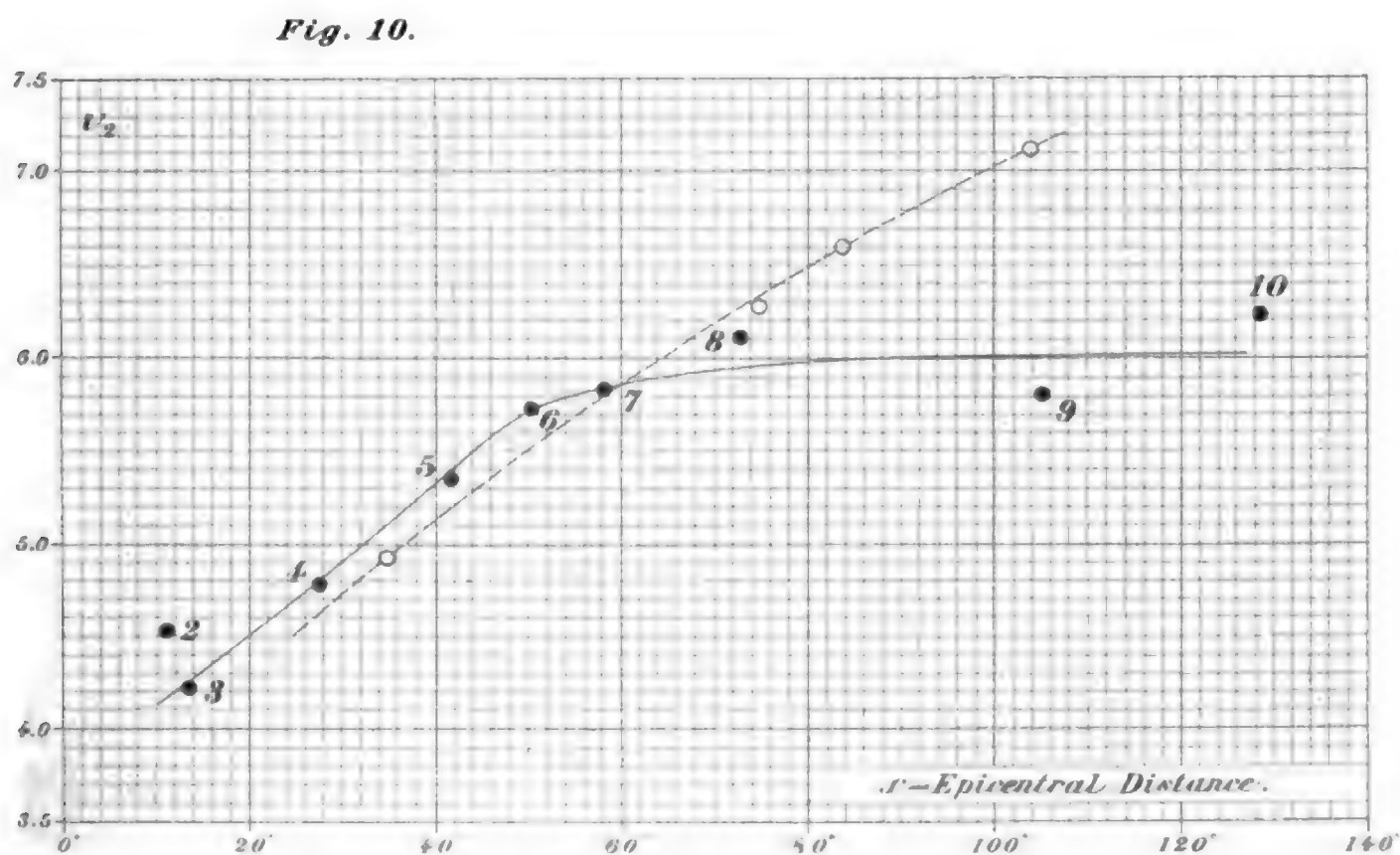
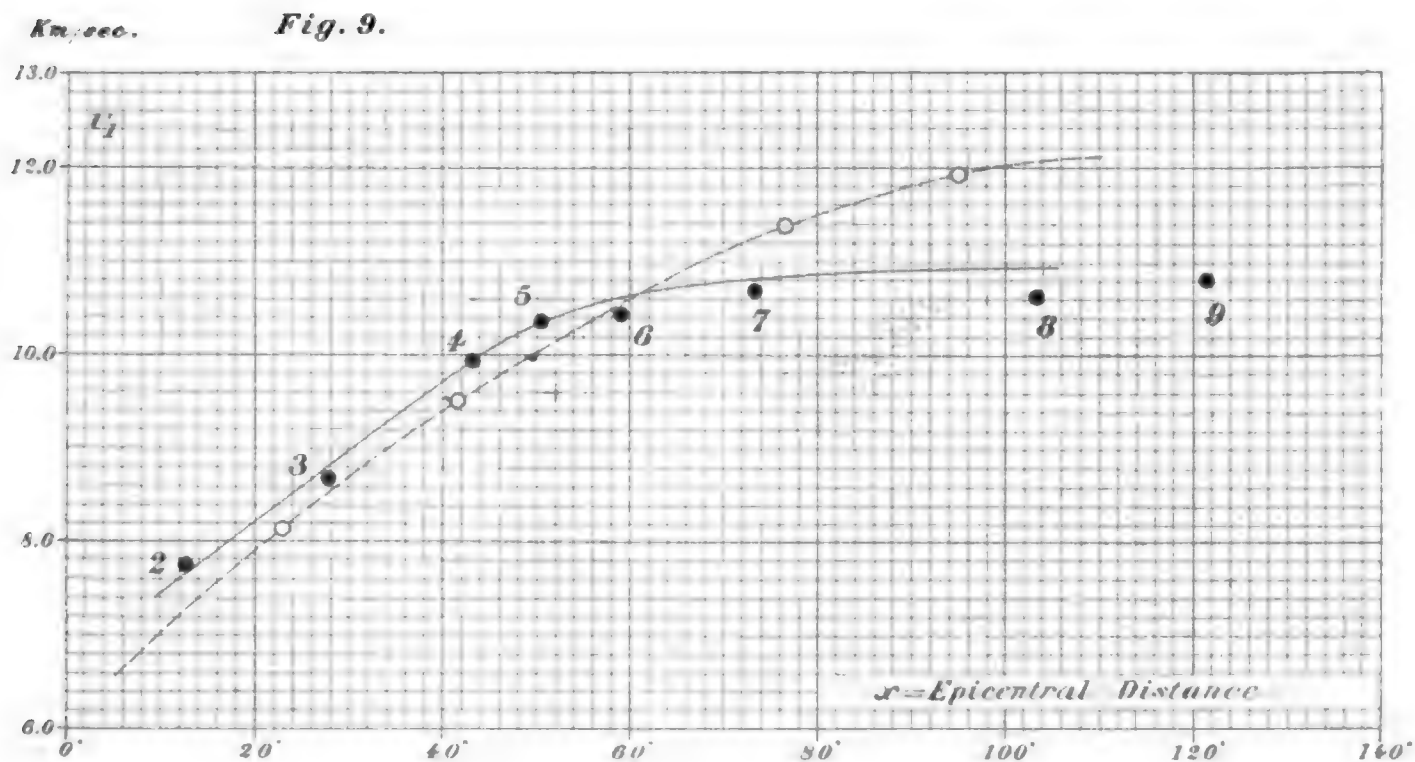


Fig. 8. Indian Eqke of 1905. Relation to the Epicentral Distance of the Time of Occurrence of the 2nd Preliminary Tremor.



Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocities of the 1st and 2nd Preliminary Tremors, Calculated by "Direct Method."



Black dots (•) and full line relate to Kangra Eqke.

Small white circle (○) and dotted line relate to San Francisco Eqke.

that the time (t_1) increased almost linearly with the distance (x) between about 30° and 120° (maximum limit).

Taking from Table IX, the mean group values of the epicentral distance and the corresponding time of occurrence of the 1st preliminary tremor, and calculating by the method of Least Squares, we find for the limits of x between $27^\circ 57'$ and $121^\circ 16'$,

$$v_1 = \mathbf{11.36} \text{ km per sec.}$$

Chapter V. Velocity of Propagation of the 2nd Preliminary Tremor.

102. Time of Commencement (t_2) and Transit Velocity (v_2) at Different Stations. The following table gives the epicentral distance (x) and the time of commencement (t_2) of the 2nd preliminary tremor for the 42 stations, whose seismograms indicated the last mentioned phase of motion with clearness; the different stations being divided, according to the epicentral distance, into a number of groups. The velocity v_2 given in the 4th column of the table has been calculated by "direct method" according to the formula

$$v_2 = \frac{x}{t_2 - t_0};$$

t_0 being the time of earthquake occurrence at the origin, assumed to be $0^h 49^m 48^s$ (G.M.T.).

Again, as will be seen from the results of the calculation of the velocity v_2 by "difference method" the times t_2 for Kodaikanal, Taungoo, and Batavia, seem to be a little too late. Accordingly these 3 stations (marked with *asterisks* in the Table) have been

excluded in deducing the mean values of the velocity v_2 ; the weight of the observations at those places, where the seismograms were apparently not quite satisfactory, being taken to be half that of the observations at the remaining places.

Table XI. Time of Commencement and Transit Velocity of the 2nd Preliminary Tremor.

Station.	Epicentral Distance = π .		Time of com- mencement of 2nd P. T. = t_2 .			v_2 Calculated by "Direct Method."
			^h	^m	^s	
Eqke Origin.	—		0	49	48	—
Delma Dun.	1°	45'	0	50	38	—
Taschkent.	11	20	0	54	26	4.52
Colaba (Bombay).	13	28	0	56	39	3.64
Barrackpur.	13	32	0	55	41	4.26
Calcutta.	13	42	0	55	09	4.74
<i>Mean.</i>	13	34	0	55	50	4.21
Kodaikanal.*	21°	35'	0	59	43	4.03
Taungoo.*	21	44	1	00	03	3.93
Tiflis.	27	26	1	00	31	4.74
5 Caucasus Stations.	27	11	1	00	22	4.76
Irkutsk.	28	28	1	00	52	4.77
<i>Mean.</i>	27	42	1	00	35	4.76
Taihoku.	39	27	1	03	25	5.36
Batavia.*	42	35	1	05	33	5.01
Jurjew.	42	49	1	04	29	5.40
Manila.	43	34	1	05	03	5.29
<i>Mean.</i>	41	57	1	04	19	5.35

TABLE XI. *Cont.*

Station.	Epicentral Distance = x .		Time of com- mencement of 2nd P. T. = t_2 .			v_2 Calculated by "Direct Method."
			^h	^m	^s	^{Km/sec.}
Tadotsu.	47°	02'	1	05	49	5.44
Upsala.	47	41	1	05	19	5.69
Kobe.	48	03	1	05	26	5.69
Osaka.	48	19	1	06	03	5.51
Laibach.	49	19	1	06	08	5.59
Messina.	49	46	1	06	15	5.60
Potsdam.	49	48	1	05	51	5.75
Triest.	49	52	1	05	43	5.80
Pola.	49	55	1	05	58	5.72
Leipzig.	50	16	1	05	53	5.79
Ischia.	50	30	1	06	14	5.69
Jena.	50	48	1	06	06	5.78
Rocca di papa.	51	15	1	06	09	5.80
Padova.	51	20	1	06	42	5.63
Tokyo.	51	26	1	06	25	5.73
Mizusawa.	51	39	1	06	28	5.74
Göttingen.	51	45	1	06	12	5.84
Querce.	51	54	1	06	24	5.79
Ximeniano.	51	55	1	05	47	6.01
Quarto-Castello.	51	56	1	06	02	5.92
<i>Mean.</i>	50	12	1	06	03	5.73
Mauritius.	55	15	1	07	03	5.93
Birmingham.	58	49	1	08	56	5.69
Paisley.	59	30	1	08	18	5.96
<i>Mean.</i>	58	06	1	08	18	5.82

TABLE XI. *Cont.*

Station.	Epicentral Distance = x .		Time of com- mencement of 2nd P. T. = t_2 .			v_2 Calculated by "Direct Method."
			^h	^m	^s	^{km/sec.}
San Fernando.	66°	54'	1	11	42	5.66
Cape Town.	85	46	1	12	27	7.01 (?)
<i>Mean.</i>	73	11	1	11	57	6.11
Cheltenham.	105	22	1	23	22	5.81
Washington.	105	17	1	23	27	5.79
<i>Mean.</i>	105	20	1	23	25	5.80
Wellington.	115	45	1	29	54	5.34
Tacubaya.	128	47	1	28	03	6.23

The relation to the epicentral distance (x) of the time (t_2) of occurrence of the 2nd preliminary tremor is illustrated in Fig. 8, from which it will be seen that up to x =about 50 the rate of increase of the time relative to the distance was a little smaller than that of simple proportion, the maximum time deviation being about 1 min. Between x =50 and x =130, the relation seems to become more nearly one of proportion.

According to Table XI, the mean values of v_2 are as follows:—

- (i) $x=11^{\circ} 20'$; $v_2=4.52^{\text{km/sec.}}$ (Tashkent).
- (ii) 13 34 4.21 (3 Indian Stations).
- (iii) 27 42 4.76 (Tiflis and 5 Caucasian Stations).
- (iv) 41 57 5.35 (Taihoku and Manila).
- (v) 50 12 5.73 (20 Stations in Japan and Central Europe).
- (vi) 58 06 5.82 (Mauritius and 2 British Stations).
- (vii) 73 11 6.11 (San Fernando and Cape Town).
- (viii) 105 20 5.80 (Cheltenham and Washington).
- (ix) 128 47 6.23 (Tacubaya).

Of the above 9 groups, the x and v_2 for (v) have been obtained by taking the means from 20 stations in Japan, Italy, Austria-Hungary, Germany, and Sweden. As is graphically represented in Fig. 10, the velocity v_2 steadily increased with the epicentral distance, till it reached a value of 5.68 km per sec. for $x=50^\circ 16'$ (Group v), the mean rate of the velocity increase being about 0.038 km per degree of the distance. For the distances over about 60° , the rate of increase of the velocity seems to become smaller. The average value of the velocity, between $x=41^\circ 57'$ and $x=128^\circ 47'$, comes out to be **5.82** km per sec.

For the sake of comparison, the case of the San Francisco earthquake of April 18, 1906, is also illustrated in Fig. 10.*

To find out the dependence, if any, of v_2 on the nature of the path of seismic propagation, I give in the succeeding §§, the results of the velocity calculation, according to the "direct" and "difference" methods, for the different groups of stations (§ 85).

103. Group 1. Tacubaya, Colaba (Bombay), Kodaikanal (Madras).

"Direct Method."

Station.	x	$t_2 - t_0$	v_2
Tacubaya.	$128^\circ 47'$	$38^m 15^s$	$6.23^{km/sec.}$
Colaba.	13 28	6 51	3.64
Kodaikanal.	21 35	9 55	4.03

* The Bulletin of the Imperial Earthquake Investigation Committee, Vol. I, No. I, p. 37.

“ Difference Method.”

Combination of Stations.	∂x	∂t_2	v_2
Tacubaya -Colaba.	115° 19'	31 ^m 24 ^s	6.80 ^{km/sec.}
„ -Kodaikanal.	107 12	28 20	7.01
Kodaikanal-Colaba.	8 07	3 04	7.27

104. Group 2. Great Britain, North Germany, Batavia.

“ Direct Method.”

Place.	x	t_2-t_0	v_2
Great Britain { Birmingham	58° 49'	19 08 ^{m s}	5.82 ^{km/sec.}
„ { Paisley.	59 30	18 30	
Mean.	59 10	18 49.	
North Germany { Potsdam.	49 48	16 03	5.79
„ { Leipzig.	50 16	16 05	
„ { Jena.	50 48	16 18	
„ { Göttingen.	51 45	16 24	
Mean.	50 39	16 13.	
Batavia.	42 35	15 45	5.01

“ Difference Method.”

Combination.	∂x	∂t_2	v_2
Great Britain-North Germany.	8° 31'	2 ^m 36 ^s	6.07 km per sec.
„ -Batavia.	16 35	3 04	10.01
North Germany-Batavia.	8 04	0 28	(?)

105. Group 3. South Austro-Hungary, North Italy, Calcutta, Taungoo, New Zealand, Tiflis, Tuschkent.

“Direct Method.”

Station.	x	$t_2 - t_0$	v_2
South Austro-Hungary. { Laibach.	49° 19'	16 ^m 20 ^s	km/sec.
Triest.	49 52	15 55	
Pola.	49 55	16 10	
Mean	49 42	16 08 ..	5.70
North Italy { Padova.	51 15	16 21	
Rocca di papa.	51 20	16 54	
Quercee.	51 54	16 36	
Ximeniano.	51 55	15 59	
Quarto Castello.	51 56	16 14	
Mean	51 40	16 25 ..	5.83
Calcutta.	13 42	5 21	4.74
Taungoo.	21 44	10 15	3.93*
Wellington.	115 45	40 06	5.34
Tiflis.	27 26	10 43	4.74
Taschkent.	11 20	4 38	4.52

“Difference Method.”

Combination of Stations.	δx	δt_2	v_2
S. Austro-Hungary-Taungoo.	27° 58'	5 ^m 53 ^s	8.80 ^{km/sec.}
„ -Tiflis.	22 16	5 25	7.61
„ -Taschkent.	38 22	11 30	6.18
„ -Calcutta.	36 00	10 47	6.18

Combination of Stations.	δx	δt_2	v_2
Wellington-S. Austro-Hungary.	66° 03'	23 ^m 58 ^s	5.10 ^{km/sec.}
„ -Calcutta.	102 03	34 45	5.44
„ -Taungoo.	94 01	29 51	5.83
„ -North Italy.	64 05	23 41	5.01
„ -Tiflis.	88 19	29 23	5.56
„ -Taschkent.	104 25	35 28	4.61
North Italy-S. Austro-Hungary.	1 58	00 17	(?)
„ -Calcutta.	37 58	11 04	6.36
„ -Taungoo.	29 56	6 10	9.00
„ -Tiflis.	24 14	5 42	7.88
„ -Taschkent.	40 20	11 47	6.34
Tiflis -Calcutta.	13 44	5 22	4.74
„ -Taungoo.	5 42	0 28	(?)
„ -Taschkent.	16 06	6 05	5.86
Taungoo -Calcutta.	8 02	4 54	3.03
„ -Taschkent.	10 24	5 37	3.43

106. Group 5. Taschkent, Jurjew (Dorpat), Upsala, Batavia.*

“ Direct Method.”

Station.	x	$t_2 - t_0$	v_2
Taschkent	11° 20'	4 ^m 38 ^s	4.52 km/sec.
Jurjew (Dorpat)	42 49	14 41	5.40
Upsala.	47 41	15 31	5.69

* Batavia excepted. (See § 104).

"Difference Method."

Combination of Stations.	δx	δt_2	v_2
Upsala—Jurjew.	4° 52'	0 ^m 50 ^s	10.82(?) km/sec
„ —Taschkent.	36 21	10 53	6.19
Jurjew — „	31 29	10 03	5.81

107. Group 6. Japan, Taihoku, Tadotsu, Kobe, Osaka, Tokyo, Mizusawa.

"Direct Method."

Place.	x	$t_2 - t_0$	v_2
Taihoku.	39° 27'	13 ^m 37 ^s	5.36 km/sec.
Tadotsu.	47 02	16 01	5.44
Kobe.	48 03	15 38	5.69
Osaka.	48 19	16 15	5.51
Tokyo.	51 26	16 37	5.73
Mizusawa.	51 39	16 40	5.74

"Difference Method."

Combination of Stations.	δx	δt_2	v_2
Tokyo. } — { Tadotsu. Mizusawa. } — { Kobe. Osaka.	3° 45'	0 ^m 40 ^s	10.40 km/sec.
„ — Taihoku.	12 06	3 01	7.43
Tadotsu. } — Kobe. } — Osaka. }	8 21	2 21	6.57

108. Group 7. Tiflis; Ischia, Messina; Ximeniano, Querce, Quarto-Castello, Rocca di papa; San Fernando; Calcutta; Wellington.

“ Direct Method ”

Stations.	x	$t_2 - t_0$	v_2
Tiflis.	27° 26'	10 ^m 43 ^s	4.74 ^{km/sec.}
Ischia, Messina.	50 08	16 27	5.65
{ Ximeniano, Querce, Quarto-Castello, Rocca di papa.	51 45	16 17	5.88
San Fernando.	66 54	21 54	5.66
Calcutta.	13 42	5 21	4.74
Wellington.	115 45	40 06	5.35

“ Difference Method.”

Combination of Stations.	δx .	δt_1	v_2
Wellington - Tiflis.	88° 19'	29 ^m 23 ^s	5.57 ^{km/sec.}
„ - Ischia, Messina.	65 37	23 39	5.14
„ - San Fernando.	48 51	18 12	4.97
„ - { Ximeniano, Querce, Quarto- Castello, Rocca di papa.	64 00	23 49	4.98
„ - Calcutta.	102 03	34 45	5.44
San Fernando - Tiflis.	39 28	11 11	6.53
„ - Ischia, Messina.	16 46	5 27	5.70
„ - { Ximeniano, Querce, Quarto- Castello, Rocca di papa.	15 09	5 37	5.00
„ - Calcutta.	53 12	16 33	5.59
Ischia, Messina- Tiflis.	22 42	5 44	7.34
„ - Calcutta.	36 26	11 06	6.08

Combination of Stations.	∂x	∂t_2	v_2
{Ximeniano, Querce, Quarto- Castello, Rocca di papa.}-Tiflis.	24° 19'	5 ^m 34 ^s	8.10 ^{km/sec.}
„ -Calcutta.	38 03	10 56	6.45
Tiflis - „	13 44	5 22	4.74

109. Group 8. Washington, Cheltenham, Tiflis, Kodaikanal, Batavia.

“ Direct Method.”

Place.	x	$t_2 - t_0$	v_2
Washington.	105° 17'	33 ^m 39 ^s	5.79 km/sec.
Cheltenham.	105 22	33 34	5.81
Tiflis.	27 26	10 43	4.74
Kodaikanal.	21 35	9 55	4.03
Batavia.	42 35	15 45	5.01

“ Difference Method.”

Combination of Stations.	∂x .	∂t_2	v_2
Washington } -Tiflis.	77° 54'	22 ^m 54 ^s	6.30 km/sec.
Cheltenham }			
„ -Kodaikanal.	83 45	23 42	6.54
„ -Batavia.	62 45	17 52	6.50
Tiflis -Kodaikanal.	5 51	0 48	13.52 (?)
Batavia -Tiflis.	15 09	5 02	5.57
„ -Kodaikanal.	21 00	5 50	6.67

110. *Single Stations :— Manila, Mauritius, Cape Town.*
“ Direct Method.”

Place.	x	t_2-t_0	v_2
Manila.	43° 34'	15 ^m 15 ^s	5.29 km/sec.
Mauritius.	55 15	17 15	5.93
Cape Town.	85 46	22 39	7.01
Irkutsk.	28 28	11 04	4.77

SUMMARY.

111. *v_2 for the different Groups, calculated by “ Direct Method.”* The values of the velocity V_2 for the different stations, calculated by “ direct method,” are collected in Table XII.

TEBLE XII. v_2 calculated by “ Direct Method.”

Place.	Epicental Distance.	v_2
<i>Group 1.</i>		
Colaba.	13° 28'	3.64 km/sec.
Kodaikanal.	21 35	4.03
Takubaya.	128 47	6.23
<i>Group 2.</i>		
Batavia.	42° 35'	5.01
North Germany.	50 36	5.79
Great Britain.	59 10	5.82
<i>Group 3.</i>		
Taschkent.	11° 20'	4.52
Calcutta.	13 42	4.74
Tiflis.	27 26	4.74
South Austro-Hungary.	49 42	5.70
North Italy.	51 40	5.83
Wellington.	115 45	5.34

Place.	Epicentral Distance	v_2
<i>Group 5.</i>		
Taschkent.	11° 20'	4.52 km/sce.
Jurjew (Dorpat)	42 49	5.40
Upsala.	47 41	5.69
<i>Group 6.</i>		
Taihoku.	39° 27'	5.36
Tadotsu.	47 02	5.44
Kobe.	48 03	5.69
Osaka.	48 19	5.51
Tokyo.	51 26	5.73
Mizusawa.	51 39	5.74
<i>Group 7.</i>		
Calcutta.	13° 42'	4.74
Tiflis.	27 26	4.74
Ischia, Messina	50 08	5.65
{ Ximeniano, Querce, Quarto-Castello, Rocca di papa.	51 45	5.88
San Fernando.	66 54	5.66
Wellington.	115 45	5.35
<i>Group 8.</i>		
Kodaikanal.	21° 35'	4.03
Tiflis.	27 26	4.74
Batavia.	42 35	5.01
Washington.	105 17	5.79
Cheltenham.	105 22	5.81
<i>Single Stations.</i>		
Irkutsk.	28° 28'	4.77
Manila.	43 34	5.29
Mauritius.	55 15	5.93
Cape Town.	85 46	7.01

Taking for the different groups the mean values of v_2 , for the x above about 40° , we find :—

Group (1)....	Mean $x=128^\circ 47'$;	$v_2=6.23$ km/sec.	(Tacubaya only).
„ (2)	„ $x= 52^\circ 25'$;	$v_2=5.65$	„
„ (3)	„ $x= 63^\circ 42'$;	$v_2=5.68$	„
„ (5)	„ $x= 45^\circ 15'$;	$v_2=5.55$	„
„ (6)	„ $x= 48^\circ 12'$;	$v_2=5.60$	„
„ (7)	„ $x= 67^\circ 15'$;	$v_2=5.68$	„
„ (8)	„ $x= 92^\circ 47'$;	$v_2=5.64$	„

Thus the Group I (Tacubaya) observation gives a velocity of 6.23 km/sec. for the distance of $x=128^\circ 47'$. For all the other groups, whose mean distance x was from $45^\circ 15'$ to $92^\circ 47'$, the velocity v_2 remained very nearly constant, varying only between 5.55 and 5.68 km/sec. Taking the average of the values of the velocity for the groups (2) to (8), we obtain, for $x=40^\circ$ to $115^\circ 45'$:—

Mean $x=61^\circ 36'$, $v_2=5.63$ km/sec. (direct method).

Again, taking only the observations relating to Great Britain, North Germany, North Italy, South Austria-Hungary, and Tokyo, and Mizusawa, we obtain :—

- (i) Great Britain, North Germany. $x=54^\circ 53'$; $v_2=5.81$ km/sec.
- (ii) North Italy, South Austria-Hungary. $x=50^\circ 41'$; $v_2=5.77$ „
- (iii) Tokyo, Mizusawa, (Japan). $x=51^\circ 33'$; $v_2=5.74$ „

Thus again, for these sets of stations, for which the distance was nearly alike ($x=50^\circ 41'$ to $54^\circ 53'$), the velocity v_2 varied only between 5.74 km/sec. for Japan to 5.81 km/sec. for Great Britain and North Germany. If, however, these slight differences in the value of v_2 denote anything, we may conclude from the above three sets, (i), (ii), and (iii), and the Group I, as follows :—The propagation velocity v_2 was greatest along the suboceanic path,

through the North Pole, and was slightly greater along the flat region path to Great Britain and North Germany than along the mountainous path to North Italy and South Austria-Hungary, being least along the path to Japan across the plateau of Tibet.

112. *Average Value of v_2 calculated by "Difference Method."*

Taking from Table XI, the mean values of the time (t_2) of commencement of the 2nd preliminary tremor corresponding to different epicentral distances over $27^\circ 42'$ (§ 102), and calculating by the Method of Least Squares, we obtain, for $x=27^\circ 42'$ to $128^\circ 47'$:—

$$v_2 = \mathbf{6.46} \text{ km/sec ;}$$

this having no particular reference to the paths of the seismic propagation.

Chapter VI. Velocities of Propagation of the Principal Portion.

113. In this Chapter I will consider the transit velocities of the vibrations at the commencement of the 3rd and 5th sections, or the 1st and 3rd phases of the principal portion, and that of the absolute maximum indicated in the Milne horizontal pendulum seismograms.

114. *Transit Velocity (v_3) of the 1st Phase of Principal Portion.* Table XIII gives for the 12 stations of Taihoku, Tadotsu, Osaka, Tokyo, Leipzig, Göttingen, Rocca di papa, Quarto-Castello, Birmingham, Cheltenham, Washington, and Tacubaya, the epicentral distance (x), the time (t_3) of commencement of the principal

portion, the time interval ($t_3 - t_0$), and the velocity (v_3) calculated by "direct method." For the remaining stations it was difficult to fix clearly the end of the 2nd preliminary tremor.

TABLE XIII. Observation of the 1st Phase of Principal Portion ; v_3 calculated by "Direct Method."

Station.	Epicentral Distance = x .	Time of comm't. of the Princ. Portion = t_3	$t_3 - t_0$	v_3 cal. by "Direct Method."
EQ. Origin.	.....	0^h49^m48^s	—	—
(i) Taihoku.	39° 27'	1 08 50	19 02 ^{m s}	3.83 ^{km/sec.}
{ Tadotsu.	47 02	1 13 31	23 43	3.68
{ Osaka.	48 19	1 12 58	23 10	3.87
{ Leipzig.	50 16	1 13 35	23 47	3.92
(ii) { Rocca di papa.	51 15	1 13 02	23 14	3.81
{ Tokyo.	51 26	1 14 07	24 19	3.90
{ Göttingen.	51 45	1 13 43	23 55	4.01
{ Quarto-Castello.	51 56	1 13 35	23 47	4.05
Mean.	50 17	1 13 30	23 42	3.92
(iii) Birmingham.	58 49	1 16 33	26 45	4.07
(iv) { Chaltenham.	105 22	1 35 33	45 45	4.27
{ Washington.	105 17	1 35 36	45 48	4.26
Mean.	105 20	1 35 35	45 47	4.27
(v) Tacubaya.	128 47	1 43 45	53 57	4.42

As will be seen from Fig. 11, the relation between the time of commencement of the principal portion (1st phase) and the epicentral distance was very nearly linear, for the limits of the latter under consideration, namely, about 40° and 130°.

As with the other velocities, v_3 calculated by "direct method"

increased with the epicentral distance, the mean values being as follows :—

$$\begin{aligned} &\{(i), (ii), \text{ and } (iii) \dots\dots\dots x = 49^{\circ}43'; v_3 = 3.94 \text{ km/sec.} \\ &\{(iv) \text{ and } (v) \dots\dots\dots x = 113.09; v_3 = 4.32 \quad ,,\end{aligned}$$

The relation to the epicentral distance of the velocity v_3 is illustrated in Fig. 12.

TABLE XIV. v_3 calculated by "Difference Method."

Combination of Stations.	Distance Difference = δx .	Time Difference = δt_3	v_3
Tacubaya — {Cheltenham. Washington.	$128^{\circ}47' - 105^{\circ}20' = 23^{\circ}27'$	^{sec.} 490	^{km/sec.} 5.31
„ — Birmingham.	„ — $58.49 = 69.58$	1,632	4.75
„ — (ii)	„ — $50.17 = 78.30$	1,815	4.81
„ — Taihoku.	„ — $39.27 = 89.20$	2,095	4.74
Cheltenham } — Birmingham.	$105.20 - 58.49 = 46.31$	1,142	4.52
Washington }			
„ — (ii)	„ — $50.17 = 55.03$	1,325	4.62
„ — Taihoku.	„ — $39.27 = 65.53$	1,605	4.56
Birmingham — (ii)	$58.49 - 50.17 = 8.32$	185	5.15
„ — Taihoku.	„ — $39.27 = 19.22$	463	4.64
(ii) — „	$50.17 - 39.27 = 10.50$	280	4.31

In the 10 combinations of the different stations given in the above table, the velocity v_3 varied between 4.31 and 5.31 km/sec. Excepting the 9th combination, for which the time difference δt_3 was too short, we obtain the following mean value of the velocity :—

$$v_3 = \mathbf{4.70 \text{ km/sec.}}$$

The increase of the velocity with the epicentral distance is in this case very slight.

115. Transit Velocity (v_3) of the 3rd Phase of Principal Portion. The 5th section, or the 3rd phase of the principal portion has been identified in the seismograms obtained at Taihoku, Manila, Tadotsu, Ōsaka, Tōkyō, Leipzig, Göttingen, Quarto-Castello, Querce, Ximeniano, Birmingham, Cheltenham, Washington, and Tacubaya. Table XV gives, for each of these 12 stations, the epicentral distance (x), the time (t_3) of commencement of the 3rd phase of principal portion; the velocity v_3 calculated according to the "direct method" being also indicated.

TABLE XV. Observation of the 3rd Phase of Principal Portion;
 v_3 Calculated by "Direct Method."

Station.	Epicentral Distance $=x$.	Time of Commencement of 3rd Ph., Principal Portion $=t_3$.	$t_3 - t_0$	v_3 calculated by "Direct Method"
Eqke. Origin.	.....	^h ^m ^s [0 49 48]	—	—
Taihoku (Formosa).	39° 27'	1 13 19	23 ^m 31 ^s	3.11 ^{km/sec.}
Manila.	43 34	1 16 15	26 27	3.05
Tadotsu.	47 02	1 18 52	29 04	3.00
Osaka.	48 19	1 19 52	30 04	2.98
Mean	47 41	1 19 22	29 34	2.99
Leipzig.	50 16	1 20 05	30 17	3.08
Tokyo {	EW Component. Tromometer (Hongo) " (Central Met.) " (Observatory.)	1 22 26	32 38	2.98
		1 21 22	31 34	
		1 21 40	31 52	
Querce	51 54	1 20 09	30 21	3.17
Quarto-Castello	51 56	1 20 54	31 06	3.09
Göttingen.	51 45	1 20 18	30 30	3.14
Ximeniano.	51 55	1 20 01	30 13	3.18
Mean	51 31	1 20 52	31 04	3.07

Station.	Epicentral Distance = x .	Time of Com- mencement of 3rd Ph., Prin- cipal Portion = t_s .	$t_s - t_0$	v_s calculated by "Direct Method."
Birmingham.	58° 49'	^h 1 ^m 25 ^s 22	^m 35 ^s 34	^{km/sec.} 3.06
Washington, D.C.	105 17	1 51 17	61 29	3.17
Cheltenham.	105 22	1 51 10	61 22	3.18
Mean	105 20	1 51 14	61 26	3.18
Tacubaya.	128 47	2 01 49	72 01	3.31

TABLE XVI. v_s calculated by "Difference Method."

Combination of Stations.		δx	δt_s	v_s
Tacubaya	- { Washington. Cheltenham.	23° 27'	^m 10 ^s 35	^{km/sec.} 4.10
"	-Birmingham.	69 58	36 27	3.55
"	- { Leipzig. Tōkyō. Florence. Göttingen.	77 16	40 57	3.49
"	-Ōsaka, Tadotsu.	81 06	42 27	3.54
"	-Manila.	85 13	45 34	3.46
"	-Taihoku.	89 20	48 30	3.41
Washington Cheltenham	-Birmingham.	46 31	25 52	3.33
"	- { Leipzig. Tōkyō. Florence Göttingen	53 49	30 22	3.28
"	-Ōsaka, Tadotsu.	57 39	31 52	3.35
"	-Manila.	61 46	34 59	3.27
"	-Taihoku.	65 53	37 55	3.22

Combination of Stations.		δx	δt_s	v_s
Birmingham	Leipzig. Tōkyō. Florence. Göttingen	7° 18'	^m 4 ^s 30	3.00 ^{km/sec.}
„	-Ōsaka, Tadotsu.	11 08	6 00	3.44
„	-Manila.	15 15	9 07	3.10
„	-Taihoku.	19 22	12 03	2.98
Leipzig Tōkyō Florence Göttingen	-Ōsaka, Tadotsu.	3 50	1 30	4.73
„	-Manila.	7 57	4 37	3.19
„	-Taihoku.	12 04	7 33	2.96
Ōsaka, Tadotsu	-Manila.	4 07	3 07	2.44
„	-Taihoku.	8 14	6 03	2.52
Manila	-Taihoku.	4 07	2 56	2.60

The mean of all the 21 values of v_s contained in the preceding table is:—

$$v_s = 3.28 \text{ km/sec. ;}$$

the epicentral distances of the stations taken into consideration being from 39° 27' to 128° 47'.

116. Transit Velocity (v_m) of the Vibrations corresponding to the Absolute Maximum in Milne Seismogram. The maximum in a Milne horizontal pendulum seismogram does not generally constitute the most active part of the real earthquake motion, being the effect due to the proper instrumental oscillations. As the natural period of a Milne seismograph is usually set at about 15 seconds, the

maximum in question probably corresponds to the middle part of the 6th section, or the 4th phase of the principal portion, in which, according to § 8 (p. 16), the predominating period is P_3 and whose amplitude is large and equal to about $\frac{2}{3}$ of that in the preceding phase. The following table is based on the data given in Professor Milne's Circular, No. 13, epitomized in the table given in § 65.

TABLE XVII. Milne Horizontal Pendulum Observations
of the "Absolute Maximum."

Station.	Epicentral Distance = x .	Time of occur- rence of Absol. Max. = t_m	$t_m - t_0$	v_m calculated by "Direct Method."
EQ. Origin.	.....	$\begin{smallmatrix} h & m & s \\ 0 & 49 & 48 = t_0 \end{smallmatrix}$	m	$km/sec.$
Bairût.	34° 41'	$\begin{smallmatrix} h & m \\ 1 & 24.5 \end{smallmatrix}$	34.7	1.85
Kew.	58 05	$\begin{smallmatrix} h & m \\ 1 & 29.2 \end{smallmatrix}$		
Edinburgh.	58 48	$\begin{smallmatrix} h & m \\ 1 & 31.5 \end{smallmatrix}$		
Shide.	58 52	$\begin{smallmatrix} h & m \\ 1 & 30.0 \end{smallmatrix}$		
Liverpool.	59 18	$\begin{smallmatrix} h & m \\ 1 & 30.6 \end{smallmatrix}$		
Paisley.	59 30	$\begin{smallmatrix} h & m \\ 1 & 30.7 \end{smallmatrix}$		
<i>Mean.</i>	58 55	1 30.4	40.6	2.69
Sau Fernando.	66 54	$\begin{smallmatrix} h & m \\ 1 & 34.0 \end{smallmatrix}$	44.2	2.80
Ponta Delgada.	79 54	$\begin{smallmatrix} h & m \\ 1 & 54.5 \end{smallmatrix}$		
Cape Town.	85 46	$\begin{smallmatrix} h & m \\ 1 & 46.0 \end{smallmatrix}$		
<i>Mean.</i>	82 50	1 50.25	60.5	2.53
Victoria, B.C.	97 42	$\begin{smallmatrix} h & m \\ 1 & 57.1 \end{smallmatrix}$		
Toronto.	101 30	$\begin{smallmatrix} h & m \\ 1 & 54.3 \end{smallmatrix}$		
Baltimore.	104 47	$\begin{smallmatrix} h & m \\ 2 & 10.0 \end{smallmatrix}$		
<i>Mean.</i>	101 20	2 0.5	70.7	2.65
Average (Bairût excepted).....				2.67

The mean value of the velocity v_m is thus **2.67** km/sec., agreeing fairly well with the value of the transit velocity of the 4th phase of the principal portion, previously obtained, namely $v_4=2.8$ km/sec.*

117. Remarks on v_1 and v_3 calculated by "Direct Method."

v_3 As shown in Fig. 12 and Table XIII (p.170), there seems to be a slight increase with the radial distance of the velocity (v_3) of the 1st phase of the principal portion; varying between 3.83 km/sec. for Taihoku ($x=39^\circ 27'$) to 4.42 km/sec. for Tacubaya ($x=128^\circ 47'$). The average rate of increase of the v_3 between the the distance limits under consideration is about 0.00686 km per degree.

Comparing the observation at the Japanese stations with those at the Middle Europe stations, we have :—

- (i) Tōkyo, Ōsaka, Tadotsu mean $x=48^\circ 56'$; $v_3=3.82$ km/sec.
- (ii) Leipzig, Rocca di papa, Göttingen, Quarto-Castello
 $x=51^\circ 18'$; $v_3=3.95$ km/sec.

The differences of the x and v_3 between (i) and (ii) are as follows:—

$$(ii)-(i) \dots \delta x = 2^\circ 22'; \delta v_3 = 0.13 \text{ km/sec.}$$

Now, according to the average rate of velocity increase as above mentioned, the increase in v_3 corresponding to $\delta x = 2^\circ 22'$ ought to be about 0.016 km/sec. Thus, if the identification of the commencement of the 1st phase of the principal portion in the different seismograms be supposed to be correct, then the velocity v_3 for Japan was slightly slower than that along the path to the Middle Europe.

v_5 According to Fig. 14 and Table XV (p.172), the velocity (v_5) of the 3rd phase of principal portion remained, for the epicent-

* The Publications, No. 23.

Fig. 13. Indian Eqke of 1905. Relation to the Epicentral Distance of the Time of Occurrence of the 3rd Phase of Principal Portion.

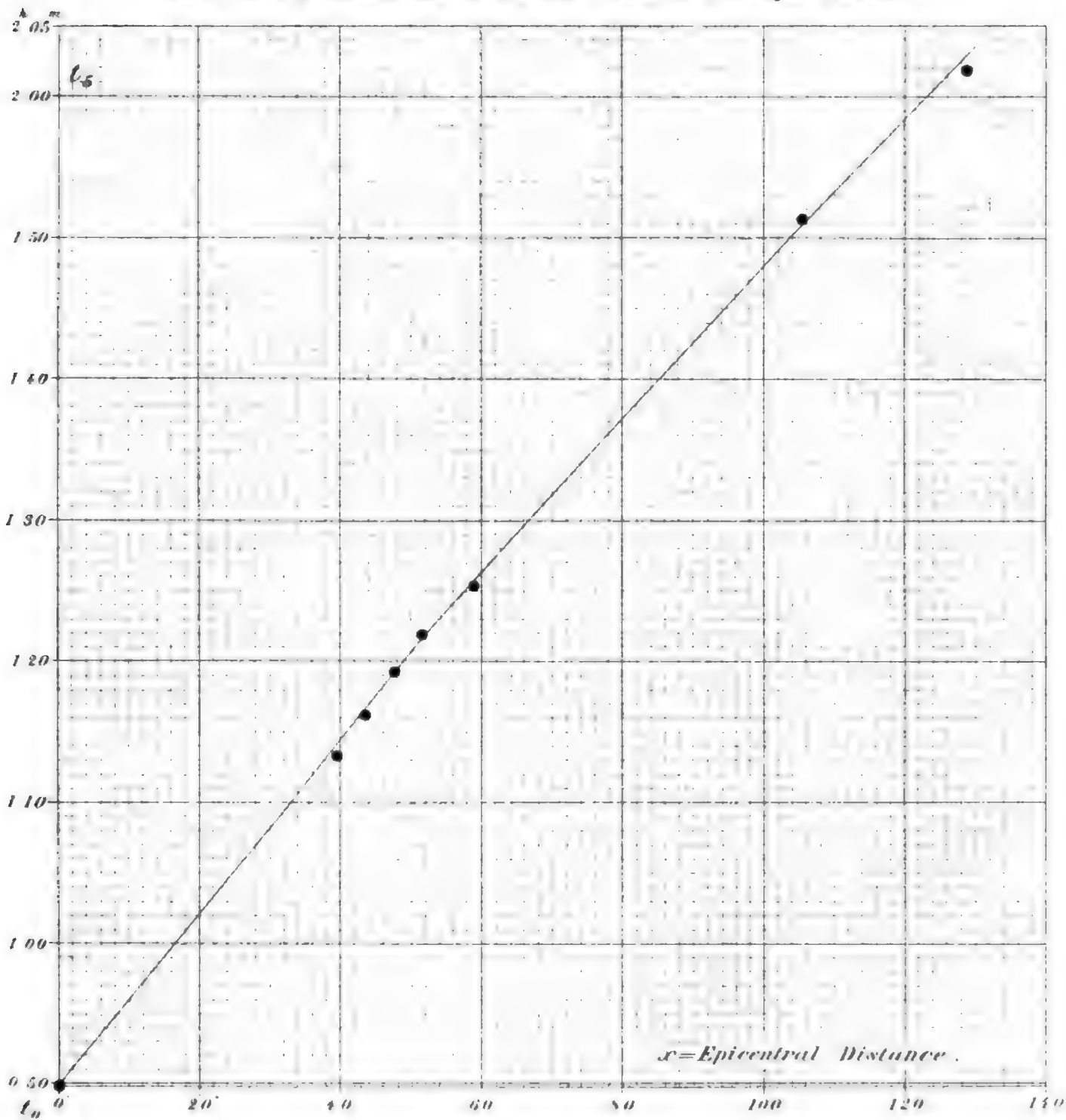


Fig. 14. Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocity of the 3rd Phase of Princ. Portion, Calculated by "Direct Method."

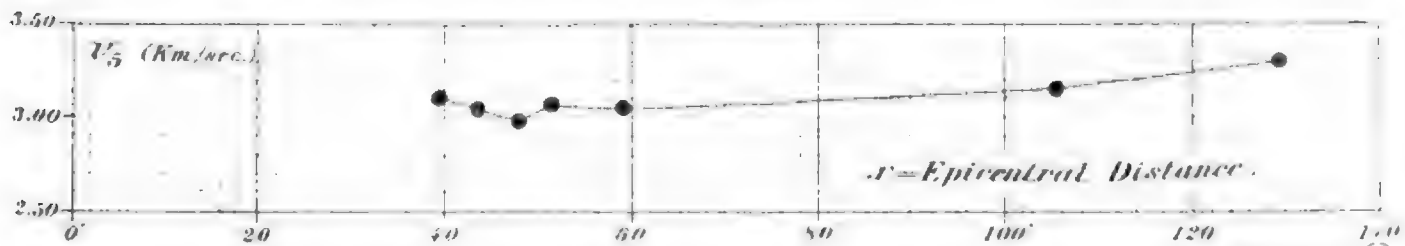


Fig. 15. Indian Earthquake of April 4, 1905.
Relation to the Epicentral *Chord* Distance of the Velocities of the
1st and 2nd Preliminary Tremors, Calculated by "Direct Method."

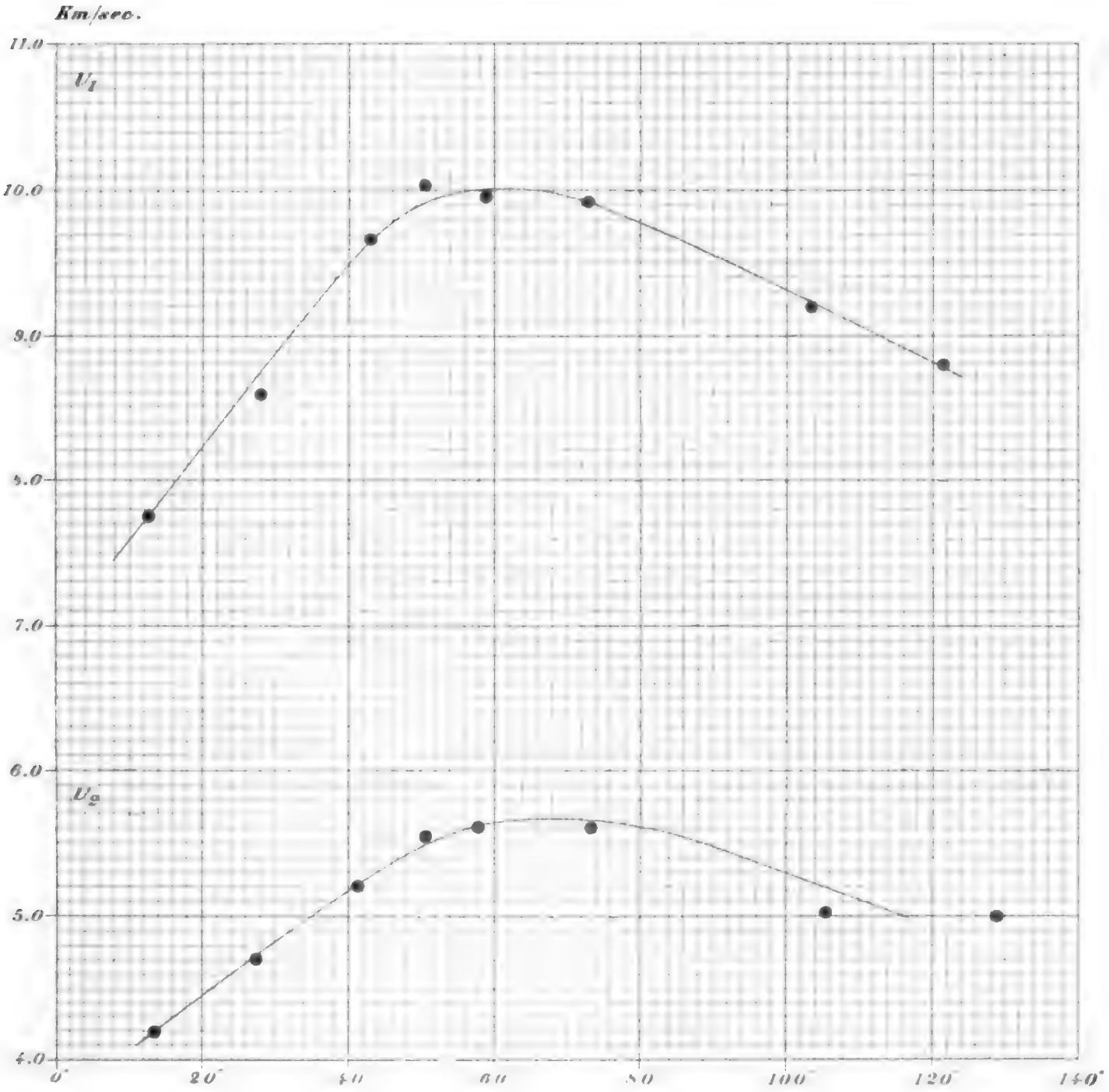


TABLE XVIII. v_1 and v_2 Calculated by "Direct Method."

Stations.	Mean Epi- central Dis- tance = x	v_1 (Along Chord)	v_2 (Along Chord)
		km/sec.	km/sec.
Taschkent, Colaba.....	12° 24'	7.76	—
Colaba, Barrackpore, Calcutta.....	13 34	.....	4.20
Irkutsk, Tiflis, and 5 other Canea- sian Stations.	27 42	.....	4.71
Tiflis, Irkutsk.	27 57	8.59	—
Taihoku, Jurjew, Manila.	41 57	.....	5.23
Taihoku, Jurjew, Manila, Belgrade, Krakau.	43 22	9.66	—
Tadotsu, Upsala, Kōbe, Ōsaka, Laibach, Messina, Potsdam, Triest, Pola, Leipzig, Ischia, Jena, Rocca di papa, Padova, Tokyo, Mizusawa, Göttingen, Querce, Ximeniano, Quarto- Castello.	50 12	.....	5.54
Same as above, with the excep- tion of Tadotsu, and with the addition of Hamburg and Strassburg.	50 24	10.04	—
Mauritius, Birmingham, Paisley...	58 06	.....	5.62
Shide, Kew, Birmingham, Liver- pool, Paisley, Edinburgh.....	58 54	9.95	—
San Fernando, Cape Town.....	73 11	9.92	5.62
Toronto, Victoria, B.C., Washing- ton, Cheltenham.....	103 03	9.22	—
Cheltenham, Washington.....	105 20	.....	5.02
Christchurch, Wellington, Porto Rico, Tacubaya.	121 21	8.80	—
Tacubaya.	128 47	.....	5.00

Thus, according to the supposition of the chord transmission the velocities v_1 and v_2 , calculated by "direct method," show each

the maximum at an epicentral distance of $x=50^\circ$ to 60° , as illustrated in Fig. 15, Pl. VIII; the greatest values of the v_1 and v_2 being 10.03 and 5.62 km/sec. The greatest values of the two velocities calculated by "direct method" on the supposition of the *arcual* transmission are 10.79 and 6.23 km/sec., respectively.

The existence of the maximum in the value of each of the two velocities v_1 and v_2 calculated by the "direct method" seems to indicate the absurdity of the supposition of the chord transmission of the vibrations composing the 1st and 2nd preliminary tremors of the teleseismic motion.

Chapter VII. Duration of the 1st Preliminary Tremor.

119. Observations at the Different Stations. The duration (y_1) of the 1st preliminary tremor for each of the 37 different stations or group of stations is given in Table XIX, the longest value being $17^m 10^s$ for Apia and Tacubaya, whose mean x is $121^\circ 58'$.

TABLE XIX. Duration of the 1st Preliminary Tremor.

Station.	Epicentral Distance = x .		Duration of 1st Prel'nary Tremor = y_1 .	
Taschkent.	11°	20'	2 ^m 05 ^s	
Colaba (Bombay).	13	28	3	31
Calcutta.	13	42	3	09
Mean	13	35	3	20

Station.	Epicentral Distance = x .		Duration of 1st Preliminary Tremor = y_1 .	
Kodaikanal.	21°	35'	3 ^m	55 ^s
Tiflis.	27	26	4	43
5 Caucasian Stations.*	27	11	4	41
Mean	26	10	4	33
Taichu.	39	051	6	14
Tainan.	39	06	6	15
Taihoku.	39	27	6	06
Batavia.	42	35	7	00
Manila.	43	34	6	38
Mean	40	45	6	27
Tadotsu.	47	02	7	00
Utsula.	47	41	6	57
Kôbe.	48	03	7	00
Ôsaka.	48	19	7	12
Lailbach.	49	19	7	17
Messina.	49	46	7	15
Potsdam.	49	48	7	05
Triest.	49	52	7	00
Pola.	49	55	7	14
Leipzig.	50	16	7	09
Ischia.	50	30	7	18
Rocca di papa.	51	15	7	18
Tokyo.	51	26	7	17
Mizusawa.	51	39	7	20
Göttingen.	51	45	7	17
Querce.	51	54	7	16
Ximeniano.	51	55	7	14

* Achalkalaki, Batum, Borshom, Derbent, Schemacha.

Station.	Epicentral Distance = x .		Duration of 1st Prel'mary Tremor = y_1 .	
Quarto Castello.	51°	56'	7 ^m	15 ^s
<i>Mean</i>	50	12	7	11
Mauritius.	55	15	8	09
Birmingham.	58	49	8	21
Paisley.	59	30	8	18
<i>Mean</i>	57	51	8	16
Cape Town.	85	46	9	57 (?)
Cheltenham.	105	22	14	44
Washington, D.C.	105	17	15	12
<i>Mean</i>	105	20	14	58
Apia (Samoa).	115	08	17	42
Tacubaya.	128	47	16	38
<i>Mean</i>	121	58	17	10

Comparing the observations at the Japanese stations with those at the Middle Europe stations, we obtain the following results :—

$$(i) \left\{ \begin{array}{l} \text{Japan :—Tadotsu, Kōbe, Ōsaka, Tokyo, Mizusawa.....} \\ \hspace{15em} \text{Mean } x=49^{\circ} 39', y_1=7^m 11^s. \\ \text{Middle Europe :—Upsala, Laibach, Messina, Potsdam, Triest,} \\ \hspace{2em} \text{Pola, Leipzig, Ischia, Rocca di papa, Göttingen, Querce,} \\ \hspace{2em} \text{Ximeniano, Quarto-Castello.....} \\ \hspace{15em} \text{Mean } x=50^{\circ} 27', y_1=7^m 12^s. \end{array} \right.$$

Again, taking only those stations, whose epicentral distance is about $51\frac{1}{2}$, we obtain the following results :—

$$(ii) \left\{ \begin{array}{l} \text{Japan:—Tokyo, Mizusawa Mean } x=51^{\circ} 30', y_1=7^m 18''. \\ \text{Middle Europe: Leipzig, Ischia, Rocca di papa, Göttingen,} \\ \quad \text{Quebec, Ximeniano, Quarto-Castello} \\ \hspace{15em} \text{Mean } x=51^{\circ} 22', y_1=7^m 15''. \end{array} \right.$$

According to (i), the duration y_1 was the same for the Japanese stations and those of Middle Europe, the mean distance for the former group being nearly $50'$ greater than for the latter. But according to (ii), the mean values of y_1 and x for the two Japanese stations of Tokyo and Mizusawa were very nearly the same as those for 7 German and Italian stations. From this it may be conjectured that the relation between x and y_1 depends only slightly on the nature of the path of the earthquake propagation.

120. Relation between the Epicentral Distance and the Duration of the 1st Preliminary Tremor. According to Table XIX, the mean group values of the epicentral distance (x) and the corresponding duration (y_1) of the 1st preliminary tremor are as follows:—

(i)	$x=11^{\circ} 20' \dots$	$y_1=2^m 05''$	(1 station)
(ii)	13 35	3 20	(2 stations)
(iii)	26 10	4 33	(7 „)
(iv)	40 45	6 27	(5 „)
(v)	50 12	7 11	(18 „)
(vi)	57 51	8 16	(3 „)
(vii)	105 20	14 58	(2 „)
(viii)	121 58	17 10	(2 „)

The variation of y_1 with x is illustrated in Fig. 16, from which it will be seen that the relation between the two quantities, for the group values of (iii) to (viii), may approximately be represented by a straight line. Assuming, therefore, a linear equation between x and y_1 for the limits under consideration, and calculating by

Method of Least Squares the values of the constants, we obtain :—

$$(1) \dots\dots\dots x^{\text{km}} = 13.77 y_1^{\text{sec.}} - 576^{\text{km}}$$

The above equation, which is to be regarded as applicable for x between about 20° and 120° , refers to the observations at different stations of the Kangra Earthquake, and differs from the formulæ given in the *Publications*, Nos. 5 and 13, which related to different earthquakes observed in Tokyo.

121. Comparison with the Turkestan and San Francisco Earthquakes. Comparing the relations between the x and y_1 obtained for the Indian earthquake with those obtained for the Turkestan (Kashgar) earthquake of 1902 and the San Francisco earthquake of 1906, we have :—

$$(1) \text{ Indian Earthquake} \dots\dots\dots x^{\text{km}} = 13.77 y_1^{\text{sec.}} - 576^{\text{km}}$$

$$(2) \text{ Turkestan } \quad \quad \quad \text{,, } * \dots\dots\dots x = 11.80 y_1 - 60$$

$$(3) \text{ San Francisco } \quad \quad \quad \text{,, } \dagger \dots\dots\dots x = 16.79 y_1 - 1618$$

The equations (2) and (3) were obtained from the observations at different seismological stations, relating respectively to the Turkestan and San Francisco earthquakes. It thus seems that the relation between the x and y_1 is not the same for different earthquakes. Of the above three equations, (2) is to be taken as of less value than the two others, being based on a less number of observations. Supposing the weight of the two equations (1) and (3) to be double that of (2), and taking the averages I obtain the following provisional result :—

$$(4) \dots\dots\dots x^{\text{km}} = 14.58 y_1^{\text{sec.}} - 890^{\text{km}}$$

which is to be regarded as holding good for x between about 20° and 140° .

* See the *Bulletin*, Vol. I, No. 4.

† " " " " , Vol. I, No. 1.

122. Comparison with Earthquakes of Near Origin. According to the results of the observations in Tokyo of the large teleseismic disturbances mentioned in § 8, the durations of the 1st and 2nd preliminary tremors are in the ratio of 100 to 95. Hence if y denote the total duration of the 1st and 2nd preliminary tremors, Equation (4) of the preceding § is transformed into the following :--

$$(5) \dots\dots\dots x^{\text{km}} = 7.06 y^{\text{sec.}} - 576^{\text{km}},$$

for $2000^{\text{km}} < x < \text{about } 16,000^{\text{km}}$

Now, for the earthquakes of near origins observed in Tokyo, whose distance varied between 70 and 900 km, the relation between the epicentral distance (x) and the total duration (y) of the preliminary tremors were as follows*:—

$$(6) \dots\dots\dots x^{\text{km}} = 7.27 y^{\text{sec.}} + 38^{\text{km}},$$

for $70^{\text{km}} < x < 900^{\text{km}}$

Thus we see that the rate of increase of the epicentral distance for 1 second of the duration of the preliminary tremor is practically the same for distant and near earthquakes, as follows :

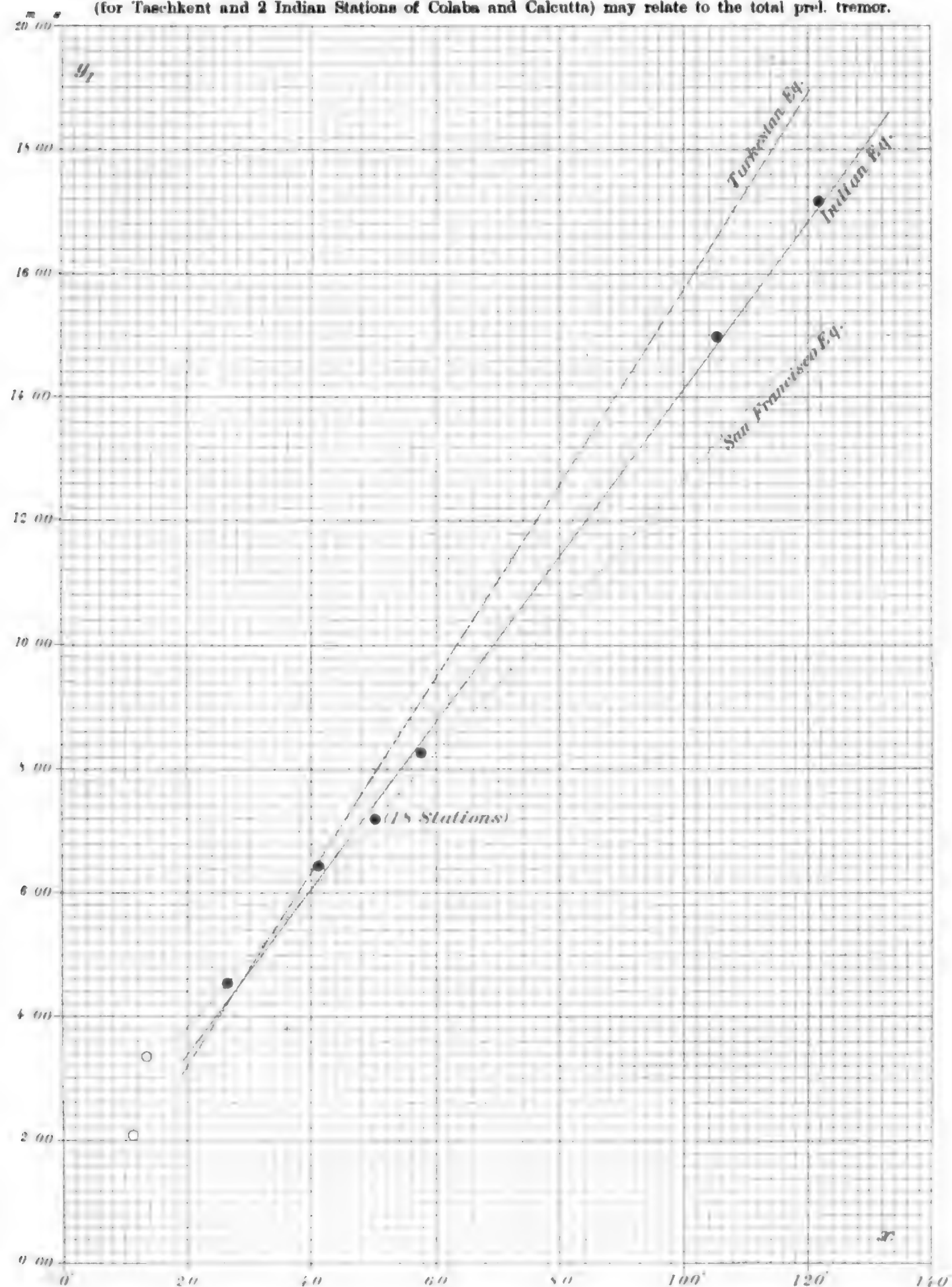
$$\left\{ \begin{array}{l} \text{Distant Eqs.} \dots\dots \frac{dx}{dy} = 7.06 \text{ km} \\ \text{Near Eqs.} \dots\dots\dots \text{,,} = 7.27 \text{ ,,} \end{array} \right.$$

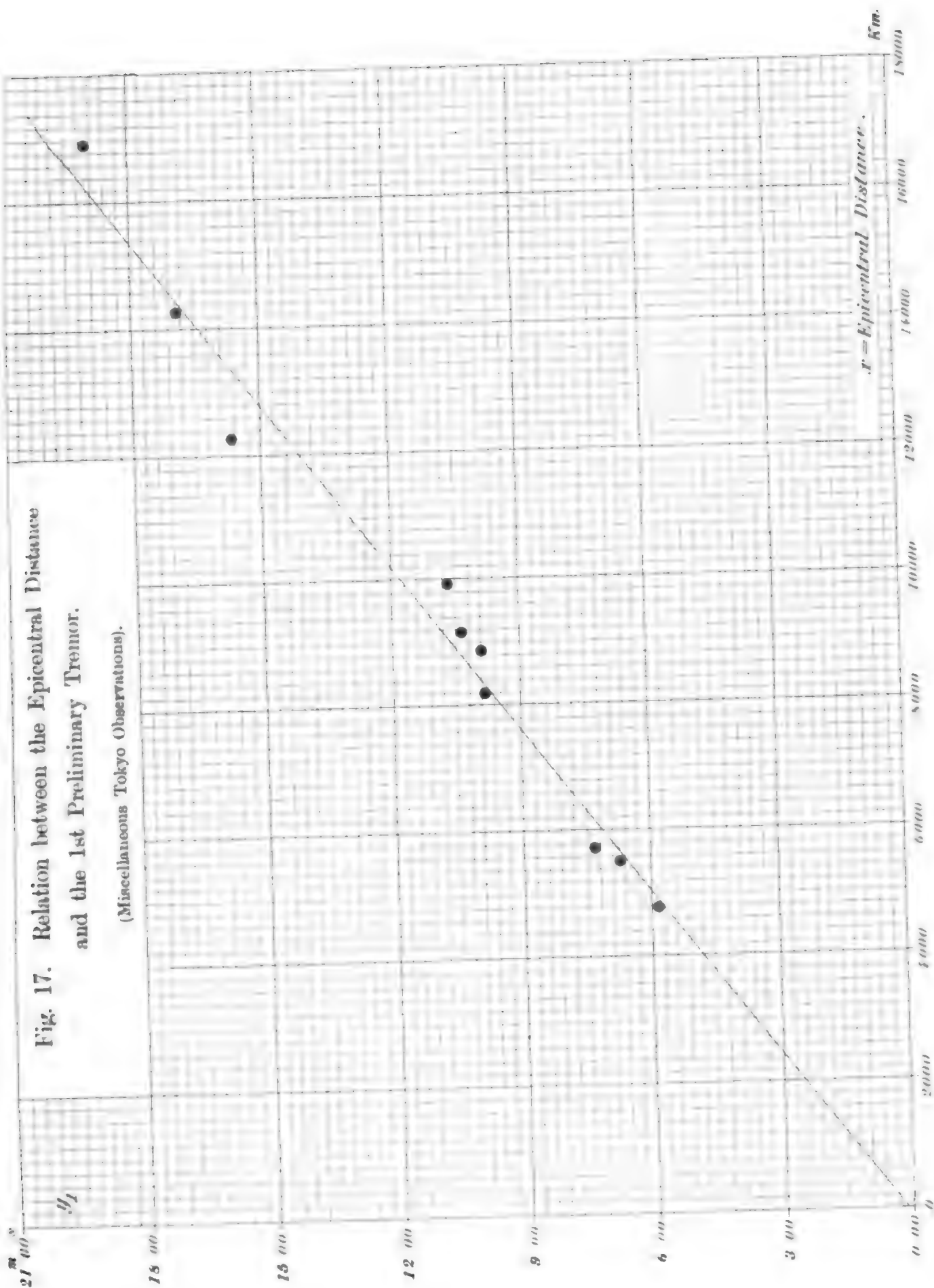
This fact probably indicates that the *rate* of separation with increase of the epicentral distance of the successive phases of the seismic motion is nearly the same for earthquakes of near and distant origins, within the limits of x under consideration.

The cases of those earthquakes, whose epicentral distance (x) is less than 70 or 100 km, must be treated specially.

Fig. 16. Relation of the Duration of the 1st Preliminary Tremor
to the Epicentral Distance.

The black dots (●) refer to Indian Eqke; 2 small white circles, which also refer to the same eqke
(for Tashkent and 2 Indian Stations of Colaba and Calcutta) may relate to the total prel. tremor.





123. Relation between x and y_1 based on the Tokyo Observations of different Telescismic Disturbances. Let us finally consider, for the sake of reference, the relation between the duration (y_1) of the 1st preliminary tremor and the epicentral distance (x), based on the horizontal pendulum observations at Tokyo of the following 10 large telescismic disturbances, whose origins are more or less definitely known.

TABLE XX. Miscellaneous Observations in Tokyo.

Earthquake.	Date.	Time of Occurrence in Tokyo $=t_1$ (G.M.T.)	Position of Epke Origin.		Epicentral Distance $=x$	Duration of 1st Prel. Tremor $=y_1$.
			Latitude.	Longitude.		
Ceram.	Sept. 29, 1899.	^h 17 ^m 11 ^s 00	6° 00' S	129° 00' E	42' 56'	^m 5 ^s 46
Turkestan.	Aug. 22, 1902.	3 09 33	39 42 N	76 00 E	49 32	6 44
India.	April. 4, 1905.	0 59 08	31 49 N	77 00 E	51 26	7 17
San Francisco.	April. 18, 1906.	13 24 35	38 15 N	123 00 W	73 41	9 49
North Japan.*	Feb. 19, 1897.	21 01 05	38 30 N	143 30 E	79 26	9 55
Calabria.	Sept. 8, 1905.	1 56 09	38 50 N	16 16 E	89 02	10 41
Aidin.	Sept. 20, 1899.	2 24 27	37 50 N	29 00 E	82 29	10 19
Guatemala.	April. 19, 1902.	2 38 47	14 30 N	91 15 W	110 23	15 40
Caracas.	Oct. 29, 1900.	9 31 52	10 00 N	68 00 W	127 19	15 55
Valparaiso.	Aug. 17, 1906.	1 00 34	31 00 S	73 00 W	152 22	18 59

The relation between the t_1 and x is, as is graphically shown in Fig. 17, very irregular, due probably to some variation in the values of the constants characterizing the linear equation for each of the different earthquakes. Calculating the constants by Method of Least Squares from the results of the observations contained in the above table we obtain :—

* This earthquake was observed at Potsdam by the present author with Rebeur Horizontal Pendulum, the time (t_1), and the duration (y_1) of the 1st preliminary tremor are the values relating to Potsdam.

$$(7) \dots\dots\dots x^{km} = \mathbf{14.42} \overset{\text{sec.}}{y_1} - \mathbf{148}^{km},$$

for $40^\circ < x < \text{about } 150^\circ;$

This formula, which is a revised form of that first given in the *Publications*, No. 5, may be regarded as being applicable to the observations made in Japan. Equation (4) given in the preceding § is to be regarded as expressing the approximate mean relation between the x and y_1 for different stations.

Chapter VIII. Periods of Vibration.

124. Quarto-Castello and Birmingham. By way of illustration let us examine the periods of vibration occurring in the Quarto-Castello and Birmingham diagrams, which were furnished by Stiattesi and Omori seismographs respectively (§§ 29 and 33). In the subsequent tables, the periods more frequently occurring are given in fat prints.

TABLE XXI. Periods of Vibration at Birmingham.

1st. prel. Tremor.	2nd prel. Tremor.	1st and 2nd Ph., P.P.	3rd Phase, Princ. Port.	4th Phase, Princ. Port.	End Portion.	Mean.
4.6 ^{sec.}	4.6 ^{sec.}	— ^{sec.}	— ^{sec.}	— ^{sec.}	— ^{sec.}	4.6 ^{sec.}
7.1	—	7.5	—	—	—	7.3
—	9.7	9.9	—	9.7	10.4	9.9
12.0	—	—	—	12.3	—	12.2
—	15.5	—	—	14.7	14.3	14.8
—	—	18.8	17.9	—	16.7	17.8
—	—	—	31.4*	—	—	31.4*
—	• —	36.6	—	—	—	36.6

(*Due to proper pendulum motion.)

TABLE XXII. Periods of Vibration at Quarto-Castello.

1st Preliminary Tremor.	2nd Preliminary Tremor.	1st and 2nd Ph. Princ. Portion.	3rd Phase, Princ. Portion.	Later Ph. of Princ. Port. End Portion.	Mean.
sec. 4.3	sec. 4.8	sec. 4.9	sec. —	sec. 4.9	sec. 4.7
6.4	—	—	6.9	—	6.7
9.1	8.6	9.1	10.0	9.1	9.2
—	11.1	—	—	12.1	11.6
—	—	—	15.0	14.5	14.8
—	—	—	—	16.7	16.7
—	—	—	—	18.8*	18.8
—	—	—	26.6	—	26.6
—	—	29.8	—	—	29.8
—	—	50.0	—	—	50.0
—	54.5	—	—	—	54.5

Comparing Tables XXI and XXII, we see that nearly all of the different periods at Birmingham are to be found also at Quarto-Castello. Again, from Table XXII it will be seen that the two periods of mean values of 4.7 and 9.2 sec. occurred in the successive phases of the Quarto-Castello seismogram. The two corresponding periods, whose mean values are 4.6 and 9.9 sec. respectively, also occurred in most of the different phases of the Birmingham seismogram.

125. Taihoku, Taichu, Tainan. Table XXIII gives the period (T) and the maximum range ($2a$) in each of the successive epochs of the earthquake motion registered at the three Formosan stations of Taihoku, Taichu, and Tainan (§§ 25, 26, and 27). The observations at these places may be regarded as examples of the seismic records furnished by horizontal pendulums of comparatively short period.

TABLE XXIII. *T* and *2a* observed at 3 Formosan Stations of Taihoku, Taichu, and Tainan. EW Component Seismograms.

	Taihoku.	Taichu.	Tainan.
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[1st Preliminary Tremor.]

	Duration = 6 ^m 6 ^s <i>T</i> = 1.07 ^{sec.} <i>2a</i> = —	Duration = 6 ^m 14 ^s <i>T</i> = — <i>2a</i> = —	Duration = 6 ^m 15 ^s <i>T</i> = — <i>2a</i> = —
2.10 „	—	—	—
3.30 „	—	—	—
4.3 „ 0.06 ^{mm.}	4.5 ^{sec.} 0.17 ^{mm.}	4.0 ^{sec.} 0.12 ^{mm.}	—
—	—	5.8 „	—
—	—	—	13.8 „ 0.08 „

[2nd Preliminary Tremor.]

	Duration = 5 ^m 25 ^s <i>T</i> = 4.5 ^{sec.} <i>2a</i> = 0.1 ^{mm.}	Duration = 5 ^m 10 ^s <i>T</i> = 4.9 ^{sec.} <i>2a</i> = 0.33 ^{mm.}	— <i>T</i> = — <i>2a</i> = —
—	—	10.2 „ 0.3 „	12.1 ^{sec.} 2.3 ^{mm.}
21 „ 0.1 „	—	—	—

[1st and 2nd Phases, Principal Portion.]

	Duration = 4 ^m 35 ^s	Duration = 4 ^m 50 ^s	{ 2nd prel. Trem., 1st and 2nd Ph., Princ. Portion . . . 9 ^m 46 ^s .
(i) During the first	2 ^m 24 ^s	2 ^m 9 ^s	—
	<i>T</i> = 4.4 ^{sec.} <i>2a</i> = 0.08 ^{mm.}	<i>T</i> = 4.4 ^{sec.} <i>2a</i> = 0.23 ^{mm.}	<i>T</i> = — <i>2a</i> = —
	10.8 „ —	9.3 „ 0.73 „	—
	41.2 „ 0.22 „	—	—
(ii) During the next	2 ^m 11 ^s	2 ^m 41 ^s	—
	—	4.6 ^{sec.} 0.23 ^{mm.}	—
	—	6.8 „ 0.50 „	—
	—	10.0 „ 2.0 „	11.8 ^{sec.} 4.6 ^{mm.}
	—	16.5 „ —	15.3 „ —
	3 ^{sec.} 3.1 ^{mm.}	—	—

	Taihoku.	Taichu.	Tainan.
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[3rd Phase, Principal Portion.]

	Duration = 5 ^m 30 ^s	Duration = 5 ^m 40 ^s	—
(i) During the first	3 ^m 29 ^s	1 ^m 44 ^s	3 ^m 8 ^s
	$T = \text{---}$ $2a = \text{---}$	$T = 9.0^{\text{sec.}}$ $2a = 12.8^{\text{mm}}$	$T = 11.8^{\text{sec.}}$ $2a = 13.8^{\text{mm}}$
	14.4 ^{sec.} 11.9 ^{mm}	— —	— —
(ii) During the next	2 ^m 1 ^s	3 ^m 56 ^s	
	5.7 ^{sec.} —	5.0 ^{sec.} 0.33 ^{mm}	
	11.8 „ 2.05 ^{mm}	8.9 „ 6.3 „	
	— —	14.8 „ 6.3 „	

[4th, etc., Phases, Principal Portion.]

	—	Duration = 3 ^m 5 ^s	Duration = 6 ^m 2 ^s
	$T = \text{---}$ $2a = \text{---}$	$T = 8.4^{\text{sec.}}$ $2a = 1.2^{\text{mm}}$	
	— —	— —	$T = 12.0^{\text{sec.}}$ $2a = 6.8^{\text{mm}}$
	— —	22.3 „ —	

End Portion.

$T = 6.6^{\text{sec.}}$ $2a = \text{---}$	$T = 5.2^{\text{sec.}}$ $2a = 0.17^{\text{mm}}$	— —
11.6 „ 0.35 ^{mm}	8.9 „ 0.5 „	— —
— —	13.6 „ 0.17 „	$T = 13.0^{\text{sec.}}$ $2a = 5.8^{\text{mm}}$

According to the above table, there is between the three stations often a marked difference in the amplitudes corresponding to a given period, being obviously the effect due to the difference in the amount of friction and the stability of the “steady mass” in the three seismographs.

The following table gives the results obtained by taking together the analyses contained in the preceding; the $2a$ is the maximum value corresponding to a given period in the three stations.

TABLE XXIV. 3 Formosan Stations. Elements of Motion.

1st Prel. Trem.		2nd Prel. Trem.		1st and 2nd Ph. Princ. Port.		3rd Phase, Princ. Port.		4th Phase, Princ. Port.		End Portion.	
Dur. = 6 ^m 12 ^s		Dur. = 5 ^m 18 ^s		Dur. = 4 ^m 43 ^s		Dur. = 5 ^m 35 ^s		Dur. = —		—	
<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>
sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.
1.07	—	—	—	—	—	—	—	—	—	—	—
2.1	—	—	—	—	—	—	—	—	—	—	—
3.3	—	—	—	—	—	—	—	—	—	—	—
4.3	0.17	4.7	0.33	4.5	0.23	5.4	0.33	—	—	5.9	0.17
5.8	—	—	—	6.8	0.50	—	—	—	—	—	—
—	—	11.2*	2.3	10.0	2.0	9.9	12.8	8.4	1.2	10.3	0.5
13.8*	0.08	—	—	—	—	11.8*	13.8	12.0*	6.8	13.3*	5.6
—	—	21.*	0.1	—	—	—	—	22.3	—	—	—
—	—	—	—	15.9	—	14.6	11.9	—	—	—	—
—	—	—	—	30.	3.1	—	—	—	—	—	—
—	—	—	—	41.2	0.22	—	—	—	—	—	—

(* Probably due to pendulum oscillations).

In the above table the periods given in fat letters are those
meaned from the values for the two or all of the three different
stations. The average values of these periods are as follows:—

4.96 sec.; (max. $2a=0.33^{\text{mm}}$, in 2nd prel. trem., and 3rd
phase of princ. port.)

9.70 „ ; (max. $2a=12.8^{\text{mm}}$, 3rd ph. of princ. portion).

15.3 „ ; („ $=11.9^{\text{mm}}$, „ „ „)

Thus the period of 4.96 sec. occurred throughout the dif-
ferent portions of the earthquake motion, the period of 9.7 sec.
occurring in the principal and end portions. The longest periods
of 30 and 41.2 sec. occurred in the 1st and 2nd phases of the
principal portion. The vibrations of average periods of 9.7 and

15.3 sec. had the greatest $2a$'s respectively of 12.8 and 11.9 mm, while those with the periods of 4.96 sec. had a much smaller $2a$ of 0.33 mm. The vibrations of the macroseismic nature, or those of $T=1.07$, 2.1, and 3.3 sec., were very small.

The values of the different periods meaned from all the phases of the earthquake motion are given in the following table; the corresponding $2a$'s being the maximum ranges among the three stations.

$T=1.07$ sec., $2a=$ — mm.

2.1	—
3.3	—
4.96	0.33
6.3	0.50
9.7	12.8
12.4	13.8
15.3	11.9
21.7	0.1
30.0	3.1
41.2	0.22

That vibrations of periods respectively equal to the two last of the above series have been registered by the short-period horizontal pendulums indicates the existence of slow movements with large amplitude.

126. Note on the Horizontal Pendulum Observations of Earthquakes at Taichu, in 1903 and 1904. For the sake of reference, I give here a few remarks on the period of vibration at Taichu based on the examination of the eastwest diagrams of 12 earthquakes observed at the latter place between Jan. 1903 and Sept. 1904. Each of these earthquakes was of a comparatively near origin, and the duration of the total preliminary tre-

mor varied between 11 and 31 sec.; the total earthquake duration varying from $7\frac{1}{2}$ to 22 min.

The average complete periods in the different phases of the earthquake motion were as follows:—

<i>Preliminary Tremor.</i>	<i>Principal Portion.</i>	<i>End Portion.</i>
sec. 0.69	sec. 3.4	sec. 3.3
4.6	4.97	4.95
8.0	7.6	
	10.3	

Thus the period of vibration most frequently happening throughout the three principal divisions of the earthquake motion varied between 4.6 and 4.97 sec., the general mean value being 4.9 sec. This is evidently identical with the period P_1 , found from the seismograms obtained in Tokyo; the value of P_1 meaned from the observations at Hongō and Hitotsubashi (both in Tokyo) being 4.6 sec. Further, the period P_1 is identical with the period Q_1 of the “pulsatory oscillations,” at Tokyo, whose mean value was found to be 4.4 sec. (See the “Publications of the Earthq. Inv. Comm.,” Nos. 5 and 13.) Hereby it is interesting to note that the horizontal pendulum diagrams obtained at the town of Taitō, which is on the eastern coast of Formosa, indicates pulsatory oscillations of an average period of about 5.0 sec.

The horizontal pendulum employed at Taichu was unable, on account of the shortness of its period of free oscillation (=15sec.), to satisfactorily register vibrations of much longer period. On this very account, however, I was enabled to recognize the existence in the *principal portion* of vibrations of P_1 period. That the long-period horizontal pendulums at Tokyo did not usually show, in cases of large earthquakes, vibrations of P_1 or P_2 period in the principal portion, is probably due to the predominance of

the record of slow period movements, the short period ones being thereby obscured.

127. Ōsaka. Table XXV gives the periods occurring in the different phases of earthquake motion at Ōsaka (§ 22).

TABLE XXV. Periods of Vibration at Ōsaka.

	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.
1st Prel. Trem.	4.6	7.8	—	—	—	—	23.8	—	—
2nd Prel. Trem.	—	—	—	—	—	20.2	25.5	{32.5 30.0	—
Princ. Port. { 1st, 2nd Ph.	—	—	—	—	—	21.7	—	—	28.3*
3rd Phase.	—	—	11.3	—	—	—	24.2	—	26.8*
4th "	—	—	10.5	—	—	22.2	—	—	—
5th "	—	—	10.2	14.4	18.5	—	—	—	—
End Portion.	—	—	10.8	14.2	—	21.7	—	—	—
W ₂	—	—	—	—	18.5	20.4	25.1	—	—
W ₃	—	—	—	—	18.5	—	—	—	—
Mean	4.6	7.8	10.7	14.3	18.5	21.2	24.7	{32.5 30.0	27.6

(*Proper pendulum oscillations).

The periods of vibration in the W_3 motion was 18.5 sec., being equal to that of the most active part in W_2 .

From Table XXV, it will be seen that the periods of average values of 21.2 and 24.7 sec. occurred in the different phases of the earthquake motion as well as in the W_2 wave, or the movement propagated along the major arc. Again, all the different periods occurring at Ōsaka can be identified in the seismograms obtained at the stations considered in the preceding §§.

128. Comparison of the NS Component Records at Tokyo and Kobe. The following table gives a comparison of the elements

of motion in the NS component recorded at Tokyo and Kobe, based on the analyses given in §§ 15 and 23.

TABLE XXVI. Periods of Vibration in the NS Component at Tokyo and Kobe. (*...Pendulum Oscillation.)

Tokyo.	Kobe.
--------	-------

[1st Preliminary Tremor.]

Duration = 7 ^m 6 ^s		Duration = 7 ^m 0 ^s	
$T = 5.2^{\text{sec.}}$	$2a = 0.14^{\text{mm}}$	$T = 4.4^{\text{sec.}}$	$2a = 0.05^{\text{mm}}$
—	—	11.5	—
15.8	0.22	—	—
20.0	0.43	—	—
—	—	—	—
29.8	0.43	—	—

[2nd Preliminary Tremor.]

Duration = 8 ^m 20 ^s		Duration = 5 ^m 44 ^s (?)	
$T = \text{—}$	$2a = \text{—}$	$T = \text{—}$	$2a = \text{—}$
—	—	30.0 ^{sec.*}	3.0 ^{mm}
33.5 ^{sec.}	1.63 ^{mm}	—	—
40.4	3.53	—	—
45.0*	3.95	—	—
55.2	—	—	—

[Principal Portion.]

$T = 10.7^{\text{sec.}}$	$2a = 1.7^{\text{mm}}$	$T = 10.7^{\text{sec.}}$	$2a = 0.19^{\text{mm}}$
19.5	1.3	18.2	2.0
22.8	0.58	23.5	1.1
—	—	28.3*	8.2

Tokyo.		Kobe.	
— ^{sec.}	— ^{mm}	33.0 ^{sec.}	2.7 ^{mm}
—	—	40.3	4.8
44.3*	8.3	—	—
—	—	55.8	2.0

[End Portion.]

12.9 ^{sec.}	0.3 ^{mm}	13.1 ^{sec.}	— ^{mm}
26.2	—	—	—

[W₂ Motion.]

12.3 ^{sec.}	— ^{mm}	—	—
18.8	0.12	—	—
25.8	0.10	—	—
29.5	—	—	—
45.0*	0.10	—	—

The following table has been formed from a comparison of the periods at the two stations as given in the preceding one.

TABLE XXVII. Mean Periods occurring at Tokyo and Kobe.
NS Component.

1st preliminary Tremor.		2nd Preliminary Tremor.		Principal Portion.		End Portion.		W ₂	
<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>
^{sec.}	^{mm}	^{sec.}	^{mm}	^{sec.}	^{mm}	^{sec.}	^{mm}	^{sec.}	^{mm}
4.8	0.14	—	—	—	—	—	—	—	—
11.5	—	—	—	10.7	1.7	—	—	—	—

1st Preliminary Tremor.		2nd Preliminary Tremor		Principal Portion.		End Portion.		W_2	
T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$
sec.	mm	sec.	mm	sec.	mm	sec.	mm	sec.	mm
—	—	—	—	—	—	13.0	0.3	12.3	—
15.8	0.22	14.8	—	—	—	—	—	—	—
20.0	0.43	—	—	18.9	2.0	—	—	18.3	0.12
—	—	—	—	23.2	1.1	—	—	—	—
—	—	—	—	—	—	26.2	—	25.8	0.10
29.8	0.43	30.3*	3.0	28.3	8.2	—	—	29.5	—
—	—	33.5	1.63	33.0	2.7	—	—	—	—
—	—	40.4	3.53	40.3	4.8	—	—	—	—
—	—	45.0*	3.95	44.3*	8.3	—	—	45.0*	0.10
—	—	55.2	—	55.8	2.0	—	—	—	—

In the above table, the amplitude corresponding to any given period is the maximum among those for the two places.

The values of the different periods meaned through all the different portions of the earthquake motion, and the corresponding maximum $2a$'s, are given in the following table; the values of the periods evidently due to the pendulum oscillations being excluded.

$T =$	4.8 sec.,	$2a =$ 0.14 mm
	11.1	1.7
	12.7	0.3
	15.3	0.22
	19.2	2.0
	24.6	1.1
	29.4	0.43
	33.3	2.7
	40.2	4.8
	55.5	2.0

Many of these periods will be found to exist also in the Ōsaka and Formosa EW records, as well as in the Birmingham and Quarto-Castello seismograms. It is to be specially noted that the two last in the above series, namely, the long periods of 40.2 and 55.5 sec. occurred respectively in the Formosa and Quarto-Castello records.

129. American and Mexican Stations. Tables XXVIII and XXIX give respectively the periods and the corresponding max. movements at the American and Mexican stations.

TABLE XXVIII. Periods and Range of Vibration.
EW Component.

Phase of motion.	Cheltenham.		Tacubaya.		Mean.	
	<i>T</i> sec.	<i>2a</i> mm	<i>T</i> sec.	<i>2a</i> mm	<i>T</i> sec.	<i>2a</i> mm
1st Prel. Tremor.	7.8	(small)	7.7	—	7.8	—
	12.3	0.05	14.2	—	13.3	0.05
2nd Prel. Tremor.	—	—	11.7	(small)	11.7	—
	14.4	0.05	—	—	14.4	0.05
	—	—	32.2	0.10	32.2	0.10
	41.0	0.10	—	—	41.0	0.10
	64.0	0.12	—	—	64.0	0.12
1st and 2nd Phases, Principal Portion.	54.0	0.12	57.4	0.10	55.7	0.12
	45.5	0.12	45.8	0.10	45.7	0.12
	—	—	37.5	0.12	37.5	0.12
	30.0	0.08	—	—	30.0	0.08
	22.4	0.12	24.8	(small)	23.6	0.12
	15.2	(small)	—	—	15.2	—

Phase of motion.	Cheltenham.		Tacubaya.		Mean	
	T sec.	$2a$ mm.	T sec.	$2a$ mm.	T sec.	$2a$ mm.
3rd Phase, Principal Portion.	19.7 *	0.83	18.1 *	0.15	—	—
	—	—	22.5	0.12	22.5	0.12
4th, etc., Phases, Principal Portion.	15.6	0.21	17.5 *	—	15.6	0.21
	20.2 *	0.36	21.2	—	—	—
W_2	18.6 *	0.28	18.0 *	0.10	—	—

TABLE XXIX. Periods and Range of Vibration. NS Component.

Phase of motion.	Cheltenham.		Washington.		Tacubaya.		Mean.	
	T sec.	$2a$ mm.	T sec.	$2a$ mm.	T sec.	$2a$ mm.	T sec.	$2a$ mm.
1st Prel. Tremor.	—	—	4.3	—	—	—	4.3	—
	7.1	—	6.3	—	8.9	—	7.4	—
	12.6	—	—	—	—	—	12.6	—
	30.3	—	—	—	—	—	30.3	—
	40.7	0.15	—	—	—	—	40.7	0.15
2nd Prel. Tremor.	8.4	—	—	—	—	—	8.4	—
	11.2	—	—	—	—	—	11.2	—
	—	—	21.4	—	—	—	21.4	—
	24.6	0.06	—	—	—	—	24.6	0.06
	30.7	0.09	28.0	—	—	—	29.4	0.09
	—	—	39.5	—	—	—	39.5	—
	46.0	0.07	—	—	—	—	46.0	0.07

* Pendulum oscillations.

Phase of motion.	Cheltenham.		Washington.		Tacubaya.		Mean.	
	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>	<i>T</i>	<i>2a</i>
	sec.	mm	sec.	mm	sec.	mm	sec.	mm
1st and 2nd Phases, Princ. Portion.	62.3	0.14	—	—	—	—	62.3	0.14
	48.0	0.09	49.5	0.05	—	—	48.8	0.09
	—	—	44.3	—	45.0	0.10	44.7	0.10
	—	—	—	—	40.3	0.10	40.3	0.10
	29.8	0.24	—	—	—	—	29.8	0.24
	—	—	27.8	0.08	—	—	27.8	0.08
	25.8	—	—	—	—	—	25.8	—
	14.1	—	—	—	—	—	14.1	—
3rd Phase, Princ. Portion.	17.5*	2.12	15.1	—	15.8*	0.30	15.1	—
	21.2	—	19.4*	1.2	—	—	21.2	—
	—	—	—	—	24.0	0.12	24.0	0.12
4th Phase, Princ. Portion., and End Portion.	16.1*	0.21	—	—	16.3*	—	16.2*	0.21
	21.6	0.05	—	—	—	—	21.6	0.05
W_2	29.0	0.06	27.0	—	—	—	28.0	0.06
	22.8	0.19	21.9	—	—	—	22.4	0.19
	18.5	0.06	—	—	19.4	0.48	19.0	0.48
	—	—	16.5	—	16.0*	0.15	16.3*	0.15
	—	—	13.5	—	—	—	13.5	—

The NS and EW components correspond, in the cases of the American and Mexican stations, approximately to the longitudinal and transverse waves, and, as will be seen from Tables XXVIII and XXIX, the vibrations in the principal portion and W_2 motion was markedly greater in the NS component. Similar periods, however, seem to occur in the two horizontal components, the notable examples being slow periods of 40 to over 60 seconds.

The mean periods of vibration deduced from the EW and NS component observations at the three stations in question are given in Table XXX; the $2a$'s being each the corresponding maximum range among the different components.

TABLE XXX. Periods and Range of Vibration. EW and NS.
Cheltenham, Washington, Tacubaya.

Phase of motion.	<i>T</i>	<i>2a.</i>	Phase of motion.	<i>T</i>	<i>2a.</i>
	sec.	mm		sec.	mm
1st Preliminary Tremor.	4.3	—	3rd Phase, Principal Portion.	15.1	—
	7.6	—		21.9	0.12
	13.0	0.05		24.0	0.12
	30.3	—		15.6	0.21
	40.7	0.15		16.2 *	0.21
	8.4	—	4th, etc. Ph., P.P. End portion.	21.6	0.05
	11.5	—			
	14.4	0.05			
	21.4	—			
	24.6	0.06			
2nd Preliminary Tremor.	29.4	0.09	<i>W</i> ₂	28.0	0.06
	32.2	0.10		22.4	0.19
	40.3	0.10		19.0	0.48
	46.0	0.07		16.3 *	0.15
				13.5	—
	63.2	0.14			
	55.7	0.12			
	48.8	0.09			
	45.2	0.12			
	40.3	0.10			
1st and 2nd Phases, Principal Portion.	37.5	0.12			
	29.9	0.24			
	27.8	0.08			
	24.7	0.12			
	14.7	—			

Finally taking the averages of the different periods from the successive phases of motion, we obtain :--

$T = 4.3$ sec.	$2a =$ — mm
7.9	—
11.5	—
14.3	0.05
21.2	0.48
24.1	0.19
31.1	0.24
37.5	0.12
40.4	0.15
46.3	0.12
55.7	0.12
63.2	0.14

Thus, in this case we have a long period of 63.2 sec., all the other periods, ranging from 4.3 sec. up to 55.7 sec., being also found at some or other of the stations considered in the preceding §§.

130. *Periods of Vibration at the different Places.* From the foregoing §§ it will be seen that many periods of vibration were common to several of the stations. To compare generally the periods occurring at different places, I give, in the four tables, XXXI to XXXIV, the period (T) and the corresponding range ($2a$) in the different phases of the earthquake motion observed at 10 stations, as follows :—

Table XXXITokyo.

„ XXXIIŌsaka, Kōbe, Tadotsu.

„ XXXIII....Birmingham, Quarto-Castello.

„ XXXIV....Potsdam, Leipzig, Göttingen, Upsala.

Besides these, Tables XXIV and XXX, already given, contain

the elements of motion in question, respectively for Taihoku, Taichu, and Tainan, and for Cheltenham, Washington, and Tacubaya. The observation of the periods at the above named 16 places are more complete than that at the others.

(* pendulum motion.)

TABLE XXXI. Periods of Vibration and Max. $2a$. *Tokyo.*

Phase of motion	EW § 14.	EW Tromometer. § 20.	EW Tromometer. Centr. M. O.	N S.	Vertical.	Mean.
	T $2a$ sec. mm.	T $2a$ sec. mm.	T $2a$ sec. mm.	T $2a$ sec. mm.	T $2a$ sec. mm.	T $2a$ sec. mm.
1st Preliminary Tremor.	4.6 0.20	4.4 0.25	4.4 0.17	5.2 0.14	4.2 —	4.5 0.25
	8.0 0.30	8.6 0.33	7.4 0.22	—	7.3 0.31	7.8 0.33
	—	—	—	15.8 0.22	—	15.8 0.22
	—	—	—	20.0 0.43	—	20.0 0.43
	24.7 0.57	—	—	—	—	24.7 0.57
	—	—	—	29.8 0.43	—	29.8 0.43
2nd Preliminary Tremor.	—	4.8 0.21	—	—	—	4.8 0.21
	9.0 Small	8.8 0.61	9.1 1.06	—	—	9.0 1.06
	—	11.8 1.05	—	—	—	11.8 1.05
	—	—	—	23.1 2.33	—	23.1 2.33
	26.5 0.97	—	—	—	—	26.5 0.97
	—	—	—	33.5 1.63	—	33.5 1.63
	37.1 4.50	—	—	—	—	37.1 4.50
	—	—	—	40.4 3.53	—	40.4 3.53
	—	—	—	45.3 3.95	—	45.3 3.95
	49.7 5.80	—	—	—	—	49.7 5.80
	54.0 —	—	—	55.2 —	—	54.6 —
	86.0 2.27	—	—	—	—	86.0 2.27

TABLE XXXI. *Cont.*

Phase of motion	E W § 14.	E W Tromometer. § 20.	E W Tromometer. Centr. M. O.	N S.	Vertical.	Mean.
	<i>T</i> 2 <i>a</i> sec. min.	<i>T</i> 2 <i>a</i> sec. min.	<i>T</i> 2 <i>a</i> sec. min.	<i>T</i> 2 <i>a</i> sec. min.	<i>T</i> 2 <i>a</i> sec. min.	<i>T</i> 2 <i>a</i> sec. min.
1st and 2nd Phases, Principal Portion.	—	9.3 0.40	8.1 0.23	—	—	8.7 0.40
	11.3 0.33	—	—	—	—	11.3 0.33
	—	16.8 0.53	—	—	—	16.8 0.53
	—	—	—	—	22.3 0.13	22.3 0.13
	27.6 6.24	29.0 0.66	—	—	29.7 0.28	28.8 6.24
	—	38.5 0.58	36.8 0.20	—	—	37.7 0.58
	—	—	—	42.5 —	—	42.5 —
	—	—	—	47.8 6.65	45.2 0.07	46.5 6.65
3rd Phase, Princ. Portion.	53.0 10.8	53.0 0.36	—	—	—	53.0 10.80
	59.0 1.30	—	—	—	—	59.0 1.30
	10.8 3.67	—	10.0 2.90	10.3 1.70	—	10.4 3.67
	16.8 2.40	—	—	—	14.1 0.29	15.5 2.40
	20.5 —	21.0 *	23.8 —	23.0 —	—	22.1 —
4th etc. Phases, Princ. Portion; End Portion.	—	34.8 Large	—	—	—	34.8 Large
	—	—	—	42.5 2.70	—	42.5 2.70
4th etc. Phases, Princ. Portion; End Portion.	—	8.2 0.24	—	—	—	8.2 0.24
	11.3 0.80	—	11.1 2.20	10.8 1.40	11.6 —	11.2 2.20
	13.2 0.72	12.1 1.67	—	12.8 0.30	—	12.7 1.67
	—	—	15.2 0.78	—	15.7 —	15.5 0.78
	—	—	—	19.5 1.30	—	19.5 1.30
	—	—	—	22.6 0.58	—	22.6 0.58
4th etc. Phases, Princ. Portion; End Portion.	—	—	—	26.2 —	—	26.2 —
	—	—	—	—	—	—

TABLE XXXII. Periods and Max.2*a*. *Ōsaka, Kōbe, Tadotsu.*

Phase of motion.	Ōsaka (EW)	Kōbe (NS)	Tadotsu (EW)	Mean.
	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm
1st Preliminary Tremor.	4.6 0.53	4.4 0.05	4.7 —	4.6 0.53
	7.8 Small	—	—	7.8 —
	—	11.5 —	10.4 —	11.0 —
	23.8 1.05	—	24.4 * 0.20	24.0 1.05
2nd Preliminary Tremor.	—	—	14.8 —	14.8 —
	20.2 1.58	—	—	20.2 1.58
	25.5 1.69	—	—	25.5 1.69
	30.0 —	30.0* 3.0	31.5 0.86	30.9 3.00
	32.5 2.53	—	36.5 0.14	36.5 0.14
1st and 2nd Ph., Princ. Portion.	21.7 1.58	—	19.0 —	20.4 —
	28.3* 4.5	—	—	28.3 4.50
	—	34.0 0.48	—	34.0 0.48
	—	40.3 4.8	39.4 1.4	39.9 4.80
	—	55.8 2.0	—	55.8 2.00
3rd Phase, Princ. Portion.	11.3 —	—	—	11.3 —
	—	18.5 2.00	—	18.5 2.00
	24.2 2.25	—	—	24.2 2.25
	26.8* 11.7	28.3 8.20	28.0 * Large.	27.7 11.70
	—	32.0 2.70	—	32.0 2.70
4th, etc. Phases, Princ. Portion; End Portion.	10.5 0.14	10.7 0.19	10.2 0.53	10.5 0.53
	14.3 0.63	13.1 —	13.6 0.27	13.7 0.63
	18.5 0.68	17.8 0.45	19.7 0.72	18.7 0.72
	22.0 1.73	23.5 1.10	—	22.8 1.73

TABLE XXXIII. Periods of Vibration and Max. $2a$.
Birmingham and Quarto-Castello.

Phase of motion.	Birmingham. (EW)	Quarto-Castello. (EW and NS)	Mean.
	T $2a$ sec. mm	T $2a$ sec. mm	T $2a$ sec. mm
1st Preliminary Tremor.	4.6 — 7.1 — — 12.0 0.035	4.3 0.04 6.4 0.02 9.1 0.07 —	4.5 0.04 6.8 0.02 9.1 0.07 12.0 0.035
2nd Preliminary Tremor.	4.6 — 9.7 0.028 — 15.5 0.083 —	4.8 0.04 8.6 0.26 11.1 0.25 — 54.5 0.51	4.7 0.04 9.2 0.26 11.1 0.25 15.5 0.083 54.5 0.51
1st and 2nd Phases, Principal Portion.	— 7.5 — 9.9 0.07 18.8 0.16 — 36.6 0.24 —	4.9 — — 9.1 0.30 — 29.8 0.44 — 50.0 0.22	4.9 — 7.5 — 9.5 0.30 18.8 0.16 29.8 0.44 36.6 0.24 50.0 0.22
3rd Phase, Principal Portion.	— — 17.9 1.56 — 31.4 2.03	6.9 0.034 10.0 0.44 15.0 0.63 26.6 0.72 —	6.9 0.034 10.0 0.44 16.5 1.56 26.6 0.72 31.4 2.03

Phase of motion.	Birmingham. (EW)		Quarto-Castello. (EW and NS)		Mean.	
	—		4.9	—	4.9	—
4th, etc. Phases,	10.1	0.04	9.1	0.38	9.6	0.38
Principal Portion ;	12.3	0.60	12.1	0.46	12.2	0.60
End Portion.	14.5	0.25	14.5	0.57	14.5	0.57
	16.7	—	16.7	0.22	16.7	0.22
	—		18.8 *	0.48	18.8*	0.48

TABLE XXXIV. Periods of Vibration and Max. $2a$.
Potsdam, Leipzig, Göttingen, Upsala.

Phase of motion.	Potsdam.		Leipzig.	Göttingen.	Upsala.	Mean.
	T	$2a$	T	T	T	T
	sec.	min	sec	sec.	sec.	sec.
1st Preliminary	5.4	0.12	4.3	4.4	4.4	4.6
Tremor.	—		7.9	8.8	8.5	8.4
	—		10.7	11.7	—	11.2
	—		—	17.3*	—	17.3*
	4.6	0.24	4.5	—	5.5	4.9
	—		9.6	10.2	7.9	9.7
	—		13.6	13.4	10.1	13.4
	—		16.2	—	12.8	15.4
2nd Preliminary	21.3	0.37	—	—	14.5	21.3
Tremor.	26.9	0.34	—	—	—	26.9
	—		38.0	—	—	38.0
	—		47.5	—	—	47.5

Phase of motion.	Potsdam.	Leipzig.	Göttingen.	Upsala.	Mean.
	<i>T</i> <i>2a</i>	<i>T</i>	<i>T</i>	<i>T</i>	<i>T</i>
	sec. mm	sec.	sec.	sec.	sec.
	4.0 —	—	—	—	4.0
	7.7 0.33	9.3	—	8.4	8.5
	—	—	—	15.9	15.9
1st and 2nd Ph.,	30.5 0.33	29.7	30.6	—	30.3
Princ. Portion.	—	36.8	36.0	—	36.4
	43.3 0.47	—	—	—	43.3
	—	49.2	48.3	—	48.8
	55.2 1.55	—	—	—	55.2
	—	9.0	9.4	9.3	9.2
	—	12.0	11.0	13.4	12.1
3rd, etc. Ph.,	16.2* 2.50	—	15.0*	—	15.6*
Princ. Portion.	19.6 1.00	20.9	—	—	20.3
	24.1 —	24.3	—	—	24.2
	29.5 1.28	—	—	—	29.5
	—	10.2	—	9.2	9.7
	—	—	—	11.9	11.9
	—	—	17.6*	14.3	14.3
	—	22.4	—	21.9	17.6*
	—	—	—	26.6	22.2
End Portion.					26.6

A glance on Tables XXIV, XXX, XXXI, XXXII, XXXIII, and XXXIV, will show that several periods existed simultaneously at the different stations. To show this relation more clearly, I have collected in the following table the mean values of the different periods and the corresponding max. $2a$'s occurring in the succes-

sive phases of the earthquake motion for the 16 stations considered before ; similar periods being placed on the same horizontal rows.†

TABLE XXXV. Kangra Earthquake. Periods of Vibration and Max. $2a$ at the different Stations. [GENERAL SUMMARY.]
(* Pendulum Oscillations.)

Phase of motion.	Tokyo.	Osaka ; Kôbe ; Tadotsu.	Taihoku ; Taichu ; Tainan.	Birm'gham ; Quarto- Castello.	Potsdam ; Leipzig ; Göttingen ; Upsala.	Chelt'ham ; Wash'gton ; Tacubaya.	Mean Periods.
	T $2a$ sec. mm	T $2a$ sec. mm	T $2a$ sec. mm	T $2a$ sec. mm	T sec.	T $2a$ sec. mm	T sec.
1st Preliminary Tremor.	4.5 0.25	4.6 0.53	4.3 0.17	4.5 0.04	4.6	4.3 —	4.5
	7.8 0.33	7.8 —	5.8 —	6.8 0.02 9.1 0.07	8.4	7.6 —	8.1 6.3
	—	11.0 —	—	12.0 0.04	11.2	—	11.4
	15.8 0.22	—	13.8 0.08	—	—	13.0 0.05	14.2
	20.0 0.43	—	—	—	17.3*	—	20.0 17.3*
	24.7 0.57	24.0 1.05	—	—	—	—	24.4
	29.8 0.43	—	—	—	—	30.3 —	30.1
	—	—	—	—	—	40.7 0.15	40.7
2nd Preliminary Tremor.	4.8 0.21	—	4.7 0.33	4.7 0.04	4.9	—	4.8
	9.0 1.06	—	—	9.2 0.26	9.7	8.4 —	9.1
	11.8 1.05	—	11.2 2.30	11.1 0.25	13.4	11.5 —	11.4 13.4
	—	14.8 —	—	15.5 0.08	15.4	14.4 0.05	15.0
	23.1 2.33	20.2 1.58	21.0 0.10	—	21.3	21.4 —	21.0 23.1
	26.5 0.97	25.5 1.69	—	—	26.9	24.6 0.06	25.9
	—	30.9 3.00	—	—	—	29.4 0.09	30.2
	33.5 1.63	—	—	—	—	32.2 0.10	32.9
	37.1 4.50	36.5 0.14	—	—	38.0	—	37.2
	40.4 3.53	—	—	—	—	40.3 0.10	40.4
	45.3 3.95	—	—	—	47.5	46.0 0.07	46.3
	49.7 5.80	—	—	—	—	—	49.7
	54.6 —	—	—	54.5 —	—	—	54.6
	86.0 2.27	—	—	—	—	—	86.0

† The $2a$ in Table XXXV is the greatest value, among the different stations, of the range of motion in EW or NS component, corresponding to a given period.

TABLE XXXV. *Cont.*

Phase of motion.	Tokyo.	Osaka ; Kobe ; Tadotsu.	Taihoku ; Taichu ; Tainan.	Birm'gham ; Quarto- Castello.	Potsdam ; Leipzig ; Göttingen ; Upsala.	Chelt'ham ; Wash'gton ; Tacubaya.	Mean Periods.
	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm	<i>T</i> <i>2a</i> sec. mm	<i>T</i> sec.	<i>T</i> <i>2a</i> sec. mm	<i>T</i> sec.
1st and 2nd Phases, Principal Portion.	8.7 0.40	—	4.5 0.23	4.9 —	4.0	—	4.5
	11.3 0.33	—	6.8 0.50	7.5 —	8.5	—	7.9
	16.8 0.53	—	10.0 2.00	9.5 0.30	—	—	10.3
	22.3 0.13	—	15.9 —	—	15.9	14.7 —	15.8
	—	20.4 —	—	18.8 0.16	—	—	20.5
	—	—	—	—	—	24.7 0.12	24.7
	28.8 6.24	28.3 4.50	30.0 3.10	29.8 0.44	30.3	29.9 0.24	29.5
	37.7 0.58	34.0 0.48	—	36.6 0.24	36.4	37.5 0.12	36.4
	42.5 —	39.9 4.80	41.2 0.22	—	—	40.3 0.10	41.0
	46.5 6.65	—	—	—	43.3	45.2 0.12	45.0
	—	—	—	50.0 0.22	48.8	48.8 0.09	49.2
	53.0 10.80	55.8 2.00	—	—	55.2	55.7 0.12	54.9
	59.0 1.30	—	—	—	—	—	59.0
	—	—	—	—	—	63.2 0.14	63.2
3rd Phase, Principal Portion.	—	—	5.4 0.33	6.9 0.03	—	—	6.2
	10.4 3.67	11.3 —	9.9 12.80	10.0 0.44	{ 9.2	—	{ 10.2
	15.5 2.40	18.5 2.00	14.6 11.90	16.5 1.56	{ 12.1	—	{ 12.1
	22.1 —	—	—	—	15.6*	15.1 —	{ 15.5
	—	{ 24.2 2.25	—	26.6 0.72	20.3	21.9 0.12	{ 18.5
	—	{ 27.7 11.70	—	31.4 2.30	24.2	24.0 0.12	{ 21.4
	—	32.0 2.70	—	—	29.5	—	{ 24.8
	34.8 Large	—	—	—	—	—	{ 27.7
	42.5 2.70	—	—	—	—	—	31.0
	—	—	—	—	—	—	34.8
	—	—	—	—	—	—	42.5
4th, etc. Ph., Principal Portion.; End Portion.	—	—	5.9 0.17	4.9 —	—	—	5.4
	8.2 0.24	10.5 0.53	8.4 1.20	9.6 0.38	9.7	—	9.3
	11.2 2.20	—	10.3 0.50	—	11.9	—	11.1
	12.7 1.67	—	12.7*6.80	12.2 0.60	—	—	12.5
	15.5 0.78	13.7 0.63	—	{ 14.5 0.57	14.3	15.6 0.21	{ 14.7
	19.5 1.30	18.7 0.72	—	{ 16.7 0.22	17.6*	—	{ 16.7
	22.6 0.58	22.8 1.73	22.3 —	18.8 0.48	—	—	18.7
	26.2 —	—	—	—	22.2	21.6 0.05	22.3
	—	—	—	—	26.6	—	26.4

The values of the different periods occurring in the Kangra earthquake (Table XXXV), obtained by taking the averages from the various phases of the earthquake motion are indicated in Table XXXVI. For the sake of comparison, I have also given in the same table the periods which were found for the following three sets of great teleseismic disturbances :—

- (i) Tokyo Horizontal Components Observation of the Caracas earthquake of Oct. 29, 1900, and the Guatemala earthquake of April 19, 1902.
- (ii) Tokyo, Ōsaka, and Manila Observations of the Valparaíso earthquake of Aug. 17, 1906. Horizontal and Vertical Components.
- (iii) E W Component Observations in Tokyo of the 10 earthquakes, namely, 3 Alaska eqkes of Sept. 4 and 10, 1899, and Oct. 9, 1900; 2 Mexico eqkes of Jan. 20, 1900, and Sept. 22, 1902; Guatemala eqke of April 19, 1902; Caracas eqke of Oct. 29, 1900; Aidin eqke of Sept. 20, 1899; Kashgar eqke of Aug. 22, 1902; and Sumatra eqke of Jan. 5, 1900.

These 10 earthquakes, together with the Guam Island eqke of Sept. 22, 1902, compose the 11 disturbances referred to in § 8. The two earthquakes of Group (i) are included in Group (iii).

TABLE XXXVI. Periods of Vibration in Kangra, Valparaiso, and other Earthquakes.

i	ii	iii	iv	Mean Values of Periods, deduced from (ii), (iii), (iv).	
Caracas and Guatemala Earthquakes (Tokyo, Horiz.)	Valparaiso Earthquake (Tokyo, Ōsaka, Manila).	10 Large Eqkes observed in Tokyo (EW Component).	Indian Eqke* (16 Stations).		
sec.	sec.	sec.	sec.	sec.	
—	—	1.5	—		
2.9	—	—	—		
—	4.0	4.1	4.7	4.3	P_1
7.9	8.4	8.9	8.6	8.6	P_2
10.2	11.4	—	11.2	11.3	$P_{2,3}$
14.8	15.1	14.5	15.1	14.9	P_3
18.4	18.3	—	—	18.3	P_4
—	—	20.0	20.7	20.4	P_5
21.2	22.6	—	—	22.6	$P_{5,6}$
26.9	26.8	24.6	25.6	25.7	P_6
—	28.7	28.3	—	25.8	P_7
—	—	—	30.1	30.1	$P_{7,8}$
32.9	32.4	—	—	32.4	P_8
—	37.1	34.4	36.4	35.9	P_9
39.5	—	42.9	41.1	42.0	P_{10}
45.4	45.0	—	45.7	45.4	P_{11}
—	—	—	49.4	49.4	P_{12}
56.0	—	54.0	54.8	54.4	P_{13}
—	—	—	59.0	59.0	P_{14}
—	67.4	66.0	63.0	65.5	P_{15}
—	—	—	⋮	⋮	⋮
—	—	—	86.0	86.0	P_{19}

(*The quick vibrations which occurred in some of the diagrams of the Kangra earthquake are noted in a subsequent §.)

From Table XXXVI, it will be seen that many periods of vibration are common to the four groups (i) to (iv). Especially the periods in the Caracas and Guatemala earthquakes observed in Tokyo were very nearly alike to those in the Valparaiso earthquake observed in Tokyo, Ōsaka, and Manila; while the periods occurring in the Kangra earthquake were similar to those found in the cases of the 10 earthquakes of group (iii). We are, therefore, justified in deducing the average values of the various periods from observations of the different earthquakes. The results thus obtained from (ii), (iii), and (iv),* are denoted in the table by the symbols $P_1, P_2, \dots, P_{15}, \dots, P_{19}$. Of these, the periods (P_1 to P_{11}) and P_{13} correspond respectively to the successive periods represented by the same letters in § 8. The periods P_{12}, P_{14}, P_{15} , and P_{19} form additions to the series before obtained.

As stated in my previous papers,† we have the following approximate relations :—

$$P_1 = \frac{P_2}{2} = \frac{P_3}{3} = \frac{P_4}{4} = \dots = \frac{P_{10}}{10} = \dots = \frac{P_n}{n},$$

where n denotes an integer, whose maximum limit is provisionally 19. According to the above assumption, P_1 is to be regarded as the fundamental or unit period of the micro-seismic movements, the different longer periods being its multiples. The most probable value of P_1 may be found as follows :—

$$P_1 = \frac{\sum_1^{15} P_n}{\sum_1^{15} n} = 4.2 \text{ sec.},$$

$P_{19} = 86$ sec. being, for the present calculation, left out of account, as it depends on a single observation. (Compare the *Publications*, No. 21, p.p. 83–84.)

* (i) is included in (iii).

† The *Publications*, No. 21.

The conclusion to be drawn, with respect to the vibration periods, from what has been said above is as follows:—The teleseismic motion is essentially the same in character at different places all over the world, and consists of a set of vibrations, whose periods are approximately equal to $P_1, P_2, P_3, \dots$. These latter may be considered as the seismic constants, not of a particular district, but of the whole earth's crust. Short period vibrations, which constitute the macro-seismic or sensible earthquake motion, are of short wave length and much depend on the nature of the ground of the observing place.

The discussions in these §§ are to be regarded only as provisional; the division of the periods of vibration into the different groups, $P_1, P_2, P_3, \dots$ being sometimes more or less arbitrary. Besides the 16 mean periods considered above there are two frequently occurring intermediate ones, respectively equal to 11.3 and 22.6 sec., and denoted in Table XXXVI by $P_{2,3}$ and $P_{5,6}$. The lengths of these two periods are in the ratio of 1 : 2. In the Kangra earthquake there was also a third intermediate period of $P_{7,8} = 30.1$ sec.

131. *Periods of Micro-seismic Vibrations in the different Phases.* According to Table XXXV, the periods of the micro-seismic vibrations occurring in the successive phases of the Kangra earthquake were as follows, those more frequently occurring being, as usual, printed in fat characters:—

TABLE XXXVII. Kangra Earthquake. Periods of Vibration occurring in the Successive Phases of the Earthquake Motion.

1st Preliminary Tremor.	2nd Preliminary Tremor.	1st and 2nd Ph., Princ. Portion.	3rd Phase, Principal Portion.	4th and 5th Ph., Princ. Portion; End Portion
P_1	P_1	P_1	P_1	P_1
P_2	P_2	P_2	—	P_2
$P_{2,3}$	$P_{2,3}$	$P_{2,3}$	$P_{2,3}$	$P_{2,3}$
P_3	P_3	P_3	P_3	P_3
—	—	—	—	P_4
P_5	P_5	P_5	P_5	—
—	—	—	—	$P_{5,6}$
P_6	P_6	P_6	P_6	P_6
—	—	—	P_7	
$P_{7,8}$	$P_{7,8}$	$P_{7,8}$	$P_{7,8}$	
—	P_8	—	—	
—	P_9	P_9	P_9	
P_{10}	P_{10}	P_{10}	P_{10}	
	P_{11}	P_{11}		
	P_{12}	P_{12}		
	P_{13}	P_{13}		
	—	P_{14}		
	—	P_{15}		
	⋮			
	P_{19}			

(*l*) According to the above table, the longest period P_{19} occurred in the 2nd preliminary tremor, while the two next longest ones, P_{13} and P_{10} , occurred only in the 1st and 2nd phases of the principal portion. Again the three next longest periods, P_{13} , P_{12} ,

and P_{11} , occurred only in the three above-named sections. On the whole the periods characterizing the 2nd preliminary tremor seem to be identical with those characterizing the 1st and 2nd phases of the principal portion, with the difference that similar periods did not have the same amplitudes in these different sections of motion, as follows:—

- (i) In the 2nd preliminary tremor, the periods of the predominating larger vibrations were P_5 to P_{12} ;
- (ii) In the 1st and 2nd phases of the principal portion, the vibrations of the periods P_1 to P_6 were small, those of the periods P_7 to P_{13} being much larger than the rest. The vibrations of P_2 and $P_{2,3}$ were here much smaller than in the preceding section.

(iii) With respect to the 1st preliminary tremor and the 3rd phase of the principal portion, we see that the periods occurring in these two sections are nearly alike; the longest period being P_{10} in each case. The principal differences between the two sections in question were as follows:—

- (i) All the vibrations, with the exception of that of the period P_1 , are much greater in the 3rd phase of the principal portion than in the 1st preliminary tremor.
- (ii) The predominating vibrations in the 1st preliminary tremor are those of the periods P_1 to P_3 .
- (iii) The most active vibrations in the 3rd phase of the principal portion are those of the periods $P_{2,3}$ to P_5 .

(iii) In the 4th and 5th phases of the principal portion and in the tail, or end portion, the predominating periods were P_2 to $P_{0,8}$.

The periods occurring throughout the successive phases of the earthquake motion were P_1 to P_6 .

132. Range of Motion ($2a$) corresponding to the different Periods, P 's. The following table, giving the ranges of motion, $2a$'s, corresponding to the different periods P 's, has been formed from the data contained in Table XXXV, and relates to the 12 places of Tokyo, Ōsaka, Kōbe, Tadotsu, Taihoku, Taichu, Tainan, Birmingham, Quarto-Castello, Cheltenham, Washington, and Tacubaya.

In Table XXXVIII the "mean $2a$ " is the average value of the max. $2a$'s in one or the other of the two horizontal components at the different stations, corresponding to a given period; the "greatest $2a$ " being the absolutely largest among these max. $2a$'s. The max. $2a$'s evidently due to the proper pendulum oscillation, which are marked each with an *asterisk*(*), have been excluded in the deduction of the mean $2a$'s.

TABLE XXXVIII. Kangra Earthquake.
 $2a$ corresponding to the different P 's.

Period.	Greatest $2a$.	Mean $2a$
P_1	^{mm} 0.53	^{mm} 0.23
P_2	1.20	0.47
$P_{2,3}$	12.90* (next greatest, 3.67)	1.28
P_3	11.90* („ „ , 2.40)	0.60
P_4	2.00	0.84
P_5	1.58	0.85
$P_{5,6}$	2.33	0.96
P_6	2.25	0.84
P_7	11.70* (next greatest, 6.24)	4.48
$P_{7,8}$	3.10	1.22

Period.	Greatest $2a$.	Mean $2a$.
P_8	2.70 ^{mm}	1.68 ^{mm}
P_9	4.50	1.01
P_{10}	4.80	1.66
P_{11}	6.65	2.70
P_{12}	5.80	2.04
P_{13}	10.80* (next greatest, 2.00)	1.06
P_{14}	1.30	1.30
P_{15}	0.14	0.14
...	...	...
P_{19}	2.27	2.27

From Table XXXVIII it will be seen that the mean $2a$'s corresponding to the 4 periods, P_1 , P_2 , P_3 , and P_4 , are roughly in the ratios of 1:2:3:4, showing an increase of the amplitude with the period. The $2a$'s for P_4 , P_5 , $P_{5.6}$, and P_6 were nearly constant, varying only between 0.84 and 0.96 mm. The amplitude seems to reach its greatest value approximately for P_{11} , as is graphically illustrated in Fig. 19. The curve, drawn with free hand through the mean positions between the different dots (•), passes through the origin of co-ordinates, which agrees with the fact that quick vibrations of macroseismic nature are very slight in the teleseismic motion. The relation between the different periods, P_1 , P_2 , ..., and the corresponding *greatest* $2a$'s, illustrated in Fig. 18, presents the same general character as in the case considered above.

The results thus far arrived at respecting the dependence of the amplitude on the period may be summarized as follows:—

In the teleseismic motion, the $2a$ increases with the period, from nearly zero to a maximum (absolute maximum in a single horizontal component = 6.65 mm) for the period $P_n = 45.4$ sec.

133. *The Order of Occurrence of the different Periods in the Principal Portion of the Earthquake Motion.* The horizontal pendulum observation of earthquakes, made in Tokyo between 1898 and 1904, has shown that, in the teleseismic motion due to a great source of disturbance, the different periods of vibration in the *principal portion* generally tend to occur in a descending order, that is to say, the vibrations at the commencement of the 1st phase (3rd section) has the longest period, those in the subsequent phases having periods of successively decreasing length.* The observation of the Kangra earthquake at the different stations also indicates the same fact, as is shown in the 3rd column of Table XXXIX, in which the periods in the 1st to 5th phases of the principal portion (3rd to 7th sections) are given in terms of the P 's in the order of their occurrence. This peculiar characteristic of the earthquake motion is to be most clearly ascertained with seismographs whose "steady mass" has a long oscillation period.

* See the *Publications*, No. 21, p.p. 84-86.

Indian Earthquake of 1905.

Relation between the Period and Amplitude.

Fig. 18..... $2a$ =Absolutely greatest max. motion.

Fig. 19..... $2a$ =mean value of max. $2a$'s.

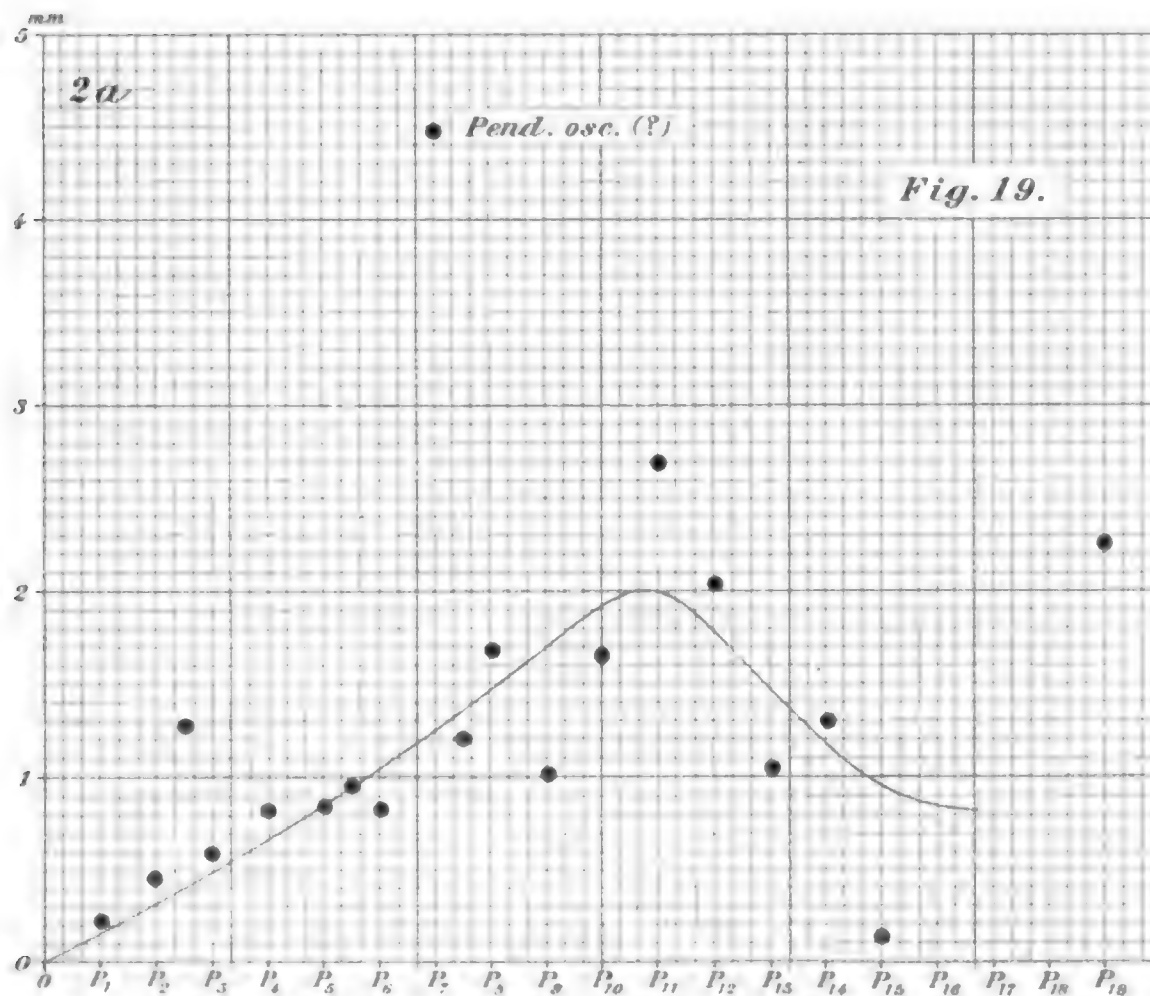
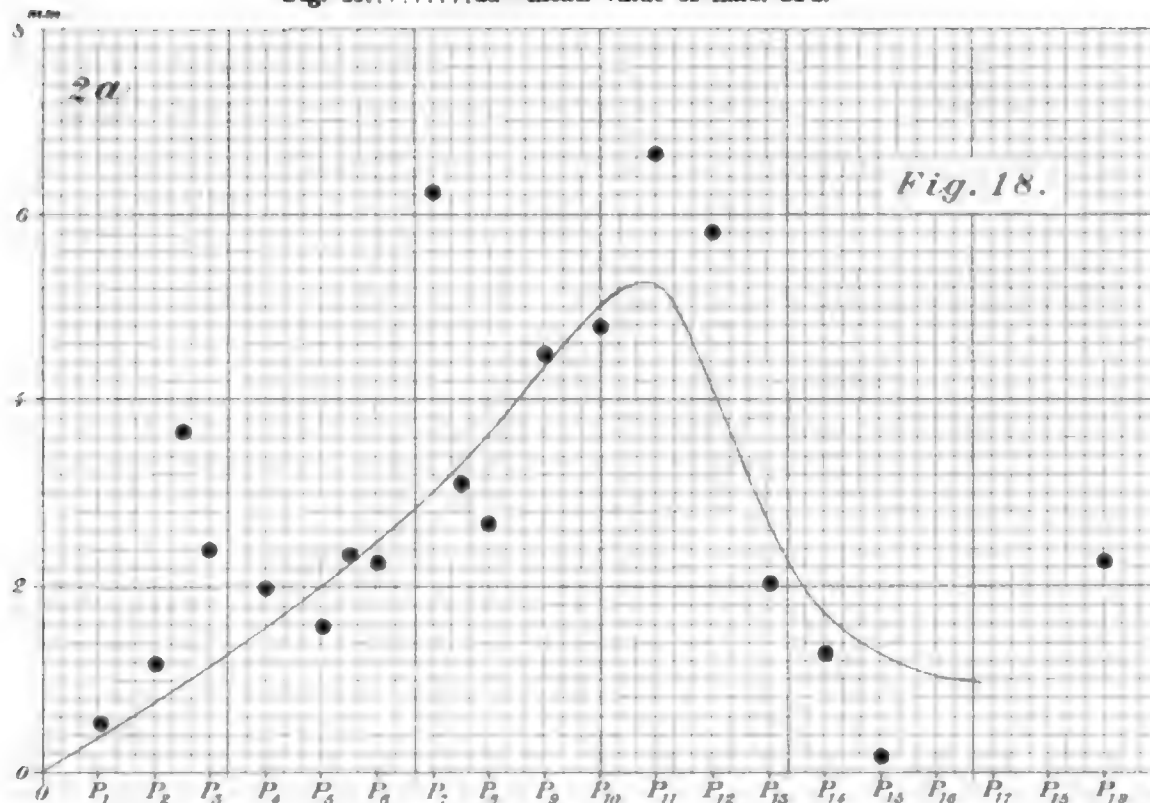


TABLE XXXIX. Kangra Earthquake. The Order of Occurrence of the different Periods in the 2nd Preliminary Tremor and in the Principal Portion of the Earthquake Motion.*

Station.	2nd Preliminary Tremor.	1st to 5th Phases, Principal Portion.
Tokyo (EW)	$P_9 P_{12} P_{13} P_{19} \left\{ \begin{matrix} P_6 \\ P_2 \end{matrix} \right\}$	$\left\{ \begin{matrix} P_{14} \\ P_{2,3} \end{matrix} \right\} P_{13} P_7 P_1 \left\{ \begin{matrix} P_{2,3} \\ P_6 \end{matrix} \right\} P_{2,3} P_{2,1} P_{2,3}$
„ (NS)	$\left\{ \begin{matrix} P_{11} \\ P_{5,6} \end{matrix} \right\} \left\{ \begin{matrix} P_8 \\ P_{1,1} \end{matrix} \right\} \left\{ \begin{matrix} P_{11} \\ P_{10} \end{matrix} \right\}$	$P_{10} P_{12} P_{10} \left\{ \begin{matrix} P_{2,3} \\ P_{5,6} \end{matrix} \right\} P_{2,3} \left\{ \begin{matrix} P_5 \\ P_{2,3} \end{matrix} \right\} P_{2,3} P_{5,6}$
„ (Vertical)	.....	$P_{11} P_{7,8} P_{5,6} P_3 P_3$
Osaka (EW)	$P_{2,3} P_8 P_6 P_{7,8}$	$P_{5,6} P_7 P_6 \left\{ \begin{matrix} P_6 \\ P_{2,3} \end{matrix} \right\} \left\{ \begin{matrix} P_{5,6} \\ P_{2,3} \end{matrix} \right\} \left\{ \begin{matrix} P_4 \\ P_3 \\ P_{2,3} \end{matrix} \right\}$
Kôbe (NS)	.....	$P_9 P_{13} P_{10} P_7 \left\{ \begin{matrix} P_8 \\ P_5 \end{matrix} \right\} \left\{ \begin{matrix} P_{5,6} \\ P_2 \end{matrix} \right\} \left\{ \begin{matrix} P_4 \\ P_{2,3} \end{matrix} \right\}$
Tadotsu (EW)	.....	$\left\{ \begin{matrix} P_{10} \\ P_4 \end{matrix} \right\} P_7 \left\{ \begin{matrix} P_5 \\ P_{2,3} \end{matrix} \right\} P_{2,3}$
Taihoku (EW)	.....	$\left\{ \begin{matrix} P_{10} \\ P_{2,3} \\ P_1 \end{matrix} \right\} P_{7,8} P_3 \left\{ \begin{matrix} P_{2,3} \\ P_1 \end{matrix} \right\}$
Washington (NS)	.....	$P_{11} P_{12} P_7 P_5 P_3$
Cheltenham (EW)	.....	$P_{15} \left\{ \begin{matrix} P_{13} \\ P_3 \end{matrix} \right\} \left\{ \begin{matrix} P_{11} \\ P_{5,6} \end{matrix} \right\} \left\{ \begin{matrix} P_{7,8} \\ P_3 \end{matrix} \right\} P_5 \left\{ \begin{matrix} P_5 \\ P_3 \end{matrix} \right\} P_3$
„ (NS)	$\left\{ \begin{matrix} P_{7,8} \\ P_2 \end{matrix} \right\} P_{2,3} P_{11} P_6$	$\left\{ \begin{matrix} P_{15} \\ P_6 \end{matrix} \right\} \left\{ \begin{matrix} P_{13} \\ P_3 \end{matrix} \right\} P_{7,8} P_4 P_5 P_3 P_3$
Tacubaya (EW)	.....	$P_{14} P_{11} P_9 P_6 P_{5,6} P_1 \left\{ \begin{matrix} P_3 \\ P_4 \\ P_5 \end{matrix} \right\}$

*The different periods occurring simultaneously in one and the same epoch are indicated by a bracket.

Station.	2nd Preliminary Tremor.	1st to 5th Phases, Principal Portion.
Tacubaya (NS)		$P_{11} P_{10} P_6 P_5 P_3 P_3$
Potsdam (EW)		$\left\{ \begin{matrix} P_8 \\ P_1 \end{matrix} \right. P_{11} \left\{ \begin{matrix} P_{7,8} \\ P_2 \\ P_1 \end{matrix} \right. P_{7,8} P_5 P_3 \left\{ \begin{matrix} P_3 \\ P_3 \end{matrix} \right.$
Göttingen (NS)		$P_{12} P_9 P_{7,8} \left\{ \begin{matrix} P_4 \\ P_{2,3} \end{matrix} \right. \left\{ \begin{matrix} P_3 \\ P_2 \end{matrix} \right. \left\{ \begin{matrix} P_3 \\ P_2 \end{matrix} \right.$

Thus it will be seen that in the majority of cases, the series began with slow vibrations of periods, P_{11} to P_{15} , thence becoming successively quicker towards the end of the principal portion. Especially, at Tokyo (EW, NS, and Vertical), Tadotsu (EW), Taihoku (EW), Cheltenham (EW and NS), Tacubaya (EW and NS), and Göttingen (NS), the succession of the different periods was in a perfect decreasing order.

It is here to be noted that what was said above respecting the order of occurrence relates only to the predominating vibrations in the principal portion, some of the small vibrations with shorter periods occurring more or less in the different sections of the earthquake motion.

134. *Periods Occurring in the 2nd Preliminary Tremor.*

The vibrations in the 2nd preliminary tremor do not generally indicate a definite order of occurrence according to the lengths of their periods. There seems, however, to exist a tendency for an increasing order of periods, as shown, for a few places, in the 2nd column of Table XXXIX.

Chapter IX. Earthquake motion propagated along the major arc and the repetition of the motion propagated along the minor arc. General remarks on the propagation velocity.

W_2 MOTION, OR THE EARTHQUAKE PROPAGATED ALONG THE MAJOR ARC.

135. Observation at Calcutta and Bombay. Let us first consider the Milne horizontal pendulum observation of the W_2 wave, or the earthquake motion propagated along the major arc, at the two Indian stations of Alipore (Calcutta) and Colaba (Bombay), whose distances from the epicentre of the Kangra earthquake were only 13 42' and 13 32' respectively.

(i) *Alipore* (Calcutta). The preliminary tremor lasted 3^m24^s, the motion being largest for the first 29^m of the principal portion.

W_2 began at 3^h 57^m 30^s, or 3^h 5^m 30^s after the commencement of the earthquake disturbance there, the 1st maximum group lasting for about 20^m:— $2a=1.6$ mm (actual reading). The principal maximum group occurred 14^m later on.

(ii) *Colaba* (Bombay). The preliminary tremor lasted 3^m31^s, the motion being greatest for the first 18½^m of the principal portion.

W_2 began at 4^h 17^m, or 3^h 23^m 52^s after the commencement of the earthquake disturbance there; the max. group ($2a=0.6$ mm, actual reading) occurring at 4^h 24^m. The motion lasted altogether for about 32^m, the last slight max. group in this portion possibly belonging to the W_3 motion.

Taking the average from the Alipore and Colaba observations, we obtain:—Time interval between the commencement of the principal portion and that of the W_2 motion=3^h 14^m 41^s, the cor-

responding epicentral distance being $13^{\circ} 37'$. In the cases of these two stations, the W_2 recorded by the seismographs seems to be the 3rd phase of the principal portion of the major arc propagation; the time interval above obtained being nearly equal to the time required by the wave of that phase in making one complete circuit of the earth. Thus, if the velocity (v_3) of the 3rd phase of the principal portion be assumed to be 3.2 km/sec., we have:—

$$\Delta t_3 = \frac{s - 2x}{v_3} = .201.7^{\text{min}} - 0.01008 x^{\text{km}},$$

in which s denotes the length of the earth's circumference, x the epicentral distance of a given station, and Δt_3 the interval between the times of arrival at the latter of the phase under consideration along the minor and the major arcs. The maximum value of Δt_3 , corresponding to $x=0$, is according to the above formula, about $3^{\text{h}} 21.^{\text{m}} 7$.

136. British Stations. As shown later on, there are, in the W_2 motion, two predominating sets of vibrations whose periods are approximately equal to P_3 (=about 20 sec.) and P_6 (=about 25 sec.) respectively; the P_3 vibrations occurring earlier than P_6 ones. Thus it is to be readily understood that the record of the W_2 motion differs much according to the oscillation period of the "steady mass" of the seismograph. This circumstance is well illustrated by the Milne horizontal pendulum seismograms obtained at the British stations. (See §§ 67–71.)

Slide records. The maximum part of W_2 in the C -pendulum record began just at the termination of that in the B -pendulum one. As the natural oscillation period of the C -pendulum was 20 sec., while that of the B -pendulum was 25 sec., this shows that, in the W_2 motion, the vibrations of period of about 25 sec. occurred earlier than those of about 20 sec.

Edinburgh record. The W_2 motion began later than the appearance of the maximum group, marked g , in Shide records. This was probably due to the shortness of the pendulum period of the Edinburgh instrument.

Kew record. The first max. group in the W_2 motion corresponds to that marked e in the Shide C -pendulum record, which occurred at $3^h 36.4^m$. The 2nd max. group, which began at $3^h 49^m$, corresponds to that marked g in the Edinburgh record.

Liverpool record. The max. group corresponds to the group c in the Shide C -pendulum record.

Paisley record. The record was nearly similar to that for Liverpool. (See Pls. XVIII and XIX, the *Publications*, No. 23.)

137. Querce. As an illustration of the identification of the corresponding epochs in the movements propagated along the minor and major arcs, I shall here briefly consider the observation at Querce. (See § 34). The W_2 motion in the NE-SW component is much smaller than that in the NW-SE component. The latter component may be summarized as follows :—

Earthquake Commencement= $0^h 59^m 8^s$.

- (a) $1^h 6^m 24^s$ Commencement of 2nd preliminary tremor.
- (b) $1 20 09$ „ 3rd phase of princ. portion.
- (c) $1 39 07$ Motion active.
- (d) $1 28 56$ Greatest max. group of pendulum oscillation.
- (e) $1 39 07$ — $2^h 1^m 7^s$ Motion more or less active.
- (f) $3 10 50$ Commencement of the W_2 motion.
- (g) $3 28 12$ Motion became larger, $2a=0.12$ mm.
- (h) $3 43 19$ „ increased, $2a=0.14$ mm.
- (i) $3 47 50$ „ most active, $2a=0.27$ mm.
- (j) $3 57 14$ End of motion.

Let us, for the sake of trial, suppose that (i) of the W_2

motion corresponds to (*d*) of the W_1 motion, or the earthquake proper; (*f*) and (*b*) being also supposed to be corresponding vibrations. On these assumptions we have:—

$$\begin{array}{rcl} \left\{ \begin{array}{l} (i) \dots\dots 3^h \ 47^m \ 50^s \\ (f) \dots\dots 3 \ 10 \ 50 \end{array} \right. & & \left\{ \begin{array}{l} (d) \dots\dots 1^h \ 28^m \ 56^s \\ (b) \dots\dots 1 \ 20 \ 09 \end{array} \right. \\ \hline \text{Difference} = & 37^m \ 00^s & \text{Difference} = \ 8^m \ 47^s \end{array}$$

Therefore:
$$\frac{(i)-(f)}{(d)-(b)} = \frac{37^m \ 00^s}{8^m \ 47^s} = 4.2 \dots\dots\dots (1)$$

This number, being, under our supposition, the ratio of the duration of the 3rd phase of the principal portion in the W_2 motion to that in the W_1 , ought to be approximately equal to the ratio of the major to the minor arc of the earth between Florence and the earthquake origin, as the duration of a given phase of the motion increases nearly in proportion to the distance. We have:—

$$\frac{\text{major arc } 308^\circ \ 06'}{\text{minor arc } 51^\circ \ 54'} = 5.2 \dots\dots\dots (2)$$

which ratio may be regarded as being sufficiently near to that of the durations previously obtained, in view of the very approximate nature of the discussion in question. As the ratio in (1), however, is greater than that in (2), it is perhaps better to regard (*f*) as corresponding to some epoch in the 2nd phase of the principal portion.

138. Tacubaya, Cheltenham, and Washington. As examples of the combination of the observations relating to the W_2 motion, at two or more neighbouring stations, let us next compare the Tacubaya, Cheltenham, and Washington records.

(i) *Comparison of EW Component Seismograms.*

TABLE XL. Times of Commencement of the different Phases of motion at Tacubaya and Cheltenham.

Phase of motion	Tacubaya.	Cheltenham.	Time difference:— Tacubaya— Cheltenham.
1st Prel. Tremor.	1 ^h 11 ^m 25 ^s	1 ^h 8 ^m 39 ^s	+ 2 ^m 46 ^s
2nd Prel. Tremor.	1 28 3	1 23 21	+ 4 42
1st Phase, Princ. Portion.	1 43 45	1 35 35	+ 8 10
2nd Phase, Princ. Portion.	1 50 27	1 39 28	+10 59
Do.	1 53 30	1 42 30	+11 0
3rd Phase, Princ. Portion.	2 1 49	1 49 12	+12 37
W_2 : Max. Phase.	2 43 46	2 58 19	-14 33

The EW component seismograms obtained at Tacubaya and Cheltenham enable us to make a fairly accurate comparison of the times of commencement of the different phases of motion at these two places. As the arcual distances of Tacubaya and Cheltenham from the centre of the earthquake disturbance are 128 47' and 105 22' respectively, the vibrations propagated along the minor arcs of the earth ought to reach the latter place earlier than the former, the reverse being the case with those propagated along the major arcs, or the W_2 waves. Now, according to the preceding table, the time-difference of arrival at Tacubaya and Cheltenham was 2^m 46^s for the commencement of the 1st preliminary tremor, thence gradually increasing up to 12^m 37^s for the 3rd phase of the principal portion. The time difference might be greater for the later phases of the same portion, but the further identification was not possible. For the maximum phase of the W_2 motion, the corresponding difference comes out, as ought to be, negative and amounted to 14^m 33^s.

(ii) *Calculation of the Transit Velocity from the seismographic records at any two places.* From the seismographic records taken at any two places at different distances from the earthquake origin, we can accurately calculate the transit velocity of the 3rd phase of the principal portion, by comparing it with the most active part in the W_2 motion, even when the clock indication at each place is slightly wrong. Thus let τ_1 denote the difference in the times of arrival at the two given stations of the 3rd phase of the principal portion of the seismic waves propagated along the minor arcs, and $(-\tau_2)$ the corresponding quantity for the waves propagated along the major arcs. If the clock indications at the two places be perfectly accurate, τ_1 ought to be equal to τ_2 , supposing the identifications of the W_1 and W_2 waves to be correct. Let $\delta\tau$ be the *relative* clock correction to be applied to τ_1 and τ_2 necessary for getting the true time differences. We then have :—

$$\left\{ \begin{array}{l} \delta\tau = -\frac{\tau_1 - \tau_2}{2} ; \\ v_s = \frac{2\delta x}{\tau_1 + \tau_2} ; \end{array} \right.$$

where v_s denotes the velocity of propagation of the 3rd phase of the principal portion, and δx is the difference between the arcual distances from the earthquake origin of the two given stations.

To apply the above equations to the cases of Tacubaya and Cheltenham, we have :

$$\left\{ \begin{array}{l} \delta x = 128^\circ 47' - 105^\circ 22' = 23^\circ 25' \\ \tau_1 = 12^m 37^s \\ -\tau_2 = -14^m 33^s \end{array} \right.$$

We find therefore :—

$$\left\{ \begin{array}{l} \delta\tau = +58 \text{ sec.} \\ v_s = 3.17 \text{ km per sec.} \end{array} \right.$$

Using this time correction, we may calculate the velocities of the different phases of the earthquake motion from the time differences between Tacubaya and Cheltenham, given in the preceding table, as follows :—

$$\left\{ \begin{array}{l} v_1 = \frac{23^\circ 25'}{(2^m 46^s) + 58^s} = 11.5 \text{ km/sec.} \\ v_2 = \frac{23^\circ 25'}{4^m 42^s + 58^s} = 7.6 \\ v_3 = \frac{23^\circ 25'}{8^m 10^s + 58^s} = 4.7 \\ v_4 = \frac{23^\circ 25'}{10^m 59^s + 58^s} = 3.6 \end{array} \right.$$

These values of the velocities agree very well with those given in a later §.

(iii) *Comparison of NS Component Seismograms.*

TABLE XLI. Times of Commencement of the different Phases of motion at Cheltenham, Washington, Tacubaya.

Phase of motion.	Cheltenham.	Washington.	Tacubaya.	Time Difference: Tacubaya— (Chelt. & Wash.)
1st Preliminary Tremor.	1 ^h 8 ^m 38 ^s	1 ^h 8 ^m 25 ^s	1 ^h 11 ^m 25 ^s	+ 2 ^m 53 ^s
2nd „ „	1 23 23	1 23 27		
1st Ph., Princ. Portion.	1 35 39	1 35 36		
3rd Ph., Princ. Portion.	1 51 10	1 51 16		
Max. Motion, in the above phase.	1 52 15	1 52 39	2 11 18	18 51
4th Ph., Princ. Portion.	2 3 2	—		
W_2 (commencement)	—	2 27 28		
W_2 (principal portion)	2 51 27	2 52 30		
W_2 (most distinct part.)	—	2 58 43	2 48 25	— 10 18

The arcual distances of Cheltenham and Washington from the earthquake origin are nearly equal to one another, being respectively $105^{\circ} 22'$ and $105^{\circ} 17'$. It is, therefore, not possible to make any calculation based on the time differences for these two places. Table XLI shows, however, that the times of arrival of the different phases of the seismic motion at these two stations were practically identical. Taking means from the two seismograms, we find :—

Cheltenham,	1st preliminary tremor.	1 ^h 8 ^m 32 ^s
	2nd „ „	1 23 25
Washington,	1st phase, principal portion.	1 35 38
Mean epicen- tral distance. = $105^{\circ} 20'$	3rd „ „ „	1 51 13
	Max. in the 3rd phase.	1 52 27
	Principal portion in W_2	2 51 59

Taking the average from Tables XL and XLI, we have :—
Difference between the times of occurrence at Tacubaya and two American stations of the most active part of the W_2 motion = $12^m 26^s$; the corresponding propagation velocity is, using the same clock correction before found.

$$v_s = \frac{23^{\circ} 27'}{12^m 26^s + 58^s} = 3.23 \text{ km/sec.}$$

139. Tokyo Observation. To identify the corresponding vibrations in the three components, I give in the following table the time of commencement, $2a$, and T , of the successive epochs in the records furnished by the two long-period horizontal pendulums and the vertical motion instrument. (See §§ 14 to 20.)

Epoch.	EW Component.			NS Component.			Vertical Component.		
	Time of occurrence.	2a	T	Time of occurrence.	2a	T	Time of occurrence.	2a	T
<i>A</i> (Beginning of 2nd P. T.)	^h ^m ^s 1 06 25	^{mm} { 2.5 5.8	^{sec} 36.4 49.7	^h ^m ^s 1 06 25	^{mm} { 2.33 3.95	^{sec} 11.6 46.0	^h ^m ^s 1 06 25	^{mm} —	^{sec} —
<i>B</i>	1 11 05	4.50	37.7	1 10 28	3.53	43.7	—	—	—
<i>C</i> (Beginning of 2nd Ph., P.P.)	1 15 44	1.08	53.0	1 16 15	3.50	42.5	1 16 45	0.07	45.2
<i>D</i> (Beginning of 3rd Ph., P.P.)	1 20 34	6.24	27.6	(Pointer went out)	—	—	1 20 31	0.28	29.7
<i>E</i>	1 22 24	2.40	16.8	—	—	—	1 22 00	0.13	22.3
<i>F</i>	1 23 31	3.67	10.3	—	—	—	1 23 07	0.29	14.7
<i>G</i>	—	—	—	1 27 02	1.70	10.3	—	—	—
<i>H</i> (Beginning of W_2)	—	—	—	2 43 37	0.10	45.0	—	—	—
<i>I</i>	3 15 08	0.067	30.0	—	—	—	—	—	—
<i>J</i>	—	—	—	3 21 17	Small	Slow.	—	—	—
<i>K</i> (1st Max. of W_2).	3 24 31	0.13	24.3	3 25 17	0.10	25.4	—	—	—
<i>L</i> (2nd Max : 3rd Ph., P.P. of W_2).	3 33 37	0.19	19.4	—	—	—	3 33 22	Small	—
<i>M</i>	—	—	—	3 36 30	0.12	19.5	3 37 31	„	19.5
<i>N</i>	4 24 52	Small	44.0	—	—	—	—	—	—

(*H*) and (*L*) in the foregoing table seem to correspond respectively to the commencement of the 1st phase and the commencement of the 3rd phase, of the principal portion of the W_2 motion. (For the identification of (*L*), or the 2nd max. group of W_2 , the reader is also referred to § 141.) According to this supposition, we obtain, by taking the means from the three components, the following value of the duration(= y_{34}) of the 1st and 2nd phases of W_2 :—

$$(\textit{L}) \dots\dots\dots 3^h 33^m 30^s$$

$$(\textit{H}) \dots\dots\dots 2 \ 43 \ 37$$

$$\text{Difference} = y_{34} = 49^m 53^s$$

As the duration (y_{34}) of the 1st and 2nd phases of the principal portion of the W_1 motion or the earthquake proper was $7^m 21^s$ (§ 20), we have

$$\frac{\eta_{34} (W_2)}{y_{34} (W_1)} = \frac{49^m 53^s}{7^m 21^s} = 6.8.$$

This ratio is not much different from the ratio of the major and minor arcs between Tokyo and the earthquake origin, namely,

$$\frac{308^\circ 34'}{51^\circ 26'} = 6.0.$$

Again, the velocity (v_3) of propagation of the 3rd phase of the principal portion may be deduced from the comparison of the W_1 and W_2 vibrations, as follows :—

$$v_3 = \frac{360^\circ - (2 \times 51^\circ 26')}{3^h 33^m 30^s - 1^h 20^m 33^s} = 3.58 \text{ km per sec.}$$

140. Osaka Observation. (See § 22). The period of the principal vibrations in the most active part of the W_2 motion was 18.5 sec., while those in the preceding phase were 25.1 and 20.4 sec.; the vibrations with periods similar to one or both of these latter occurring in the 1st and 2nd preliminary tremors, and the 1st, 2nd, and 4th phases of the principal portion, of the W_1 motion, or the earthquake proper. The diagram did not indicate, in the 3rd phase of the principal portion, the vibrations with a period of exactly 18.5 sec.; but it is likely that the existence of such movements there was masked by large proper pendulum oscillations which partly confused the record.

The times of occurrence of the first feeble and the most active parts in the W_2 motion, denoted by t'_4 and t'_5 were respectively as follows :—

$$t'_4 = 3^h 22^m 30^s, \quad t'_5 = 3^h 40^m 56^s;$$

the time difference, $t'_3 - t'_1$, being $18^m 26^s$. t'_1 and t'_3 may probably be taken as marking approximately the commencements respectively of the 2nd and 3rd phases of the principal portion of the W_2 motion; the corresponding times in the earthquake proper (W_1), denoted by t_1 and t_3 , being respectively

$$t_1 = 1^h 16^m 51^s \text{ (approximate), } t_3 = 1^h 20^m 9^s;$$

The difference, $t_3 - t_1$, is $3^m 18^s$.

Now the areal distances between Osaka and the earthquake origin are as follows:—

$$\begin{cases} x = 48^\circ 19' & \text{..... Along the minor arc.} \\ x' = 360^\circ - x = 311^\circ 41' & \text{..... „ „ major arc.} \end{cases}$$

We thus obtain:—

$$\frac{360^\circ - x}{x} = 6.5; \quad \frac{t'_3 - t'_1}{t_3 - t_1} = 5.6.$$

The approximate equality of these two ratios tends to prove that the assumed identifications of the phases in the W_2 and W_1 movements are roughly correct.

Under this supposition, the velocities, v_1 and v_3 , respectively corresponding to the commencements of the 2nd and 3rd phases of the principal portion may be deduced from the observation of W_1 and W_2 movements, as follows:—

$$\begin{cases} v_1 = \frac{x' - x}{t'_1 - t_1} = \frac{263^\circ 22'}{2^h 5^m 39^s} = 3.88 \text{ km/sec.} \\ v_3 = \frac{x' - x}{t'_3 - t_3} = \frac{263^\circ 22'}{2^h 20^m 47^s} = 3.47 \text{ „} \end{cases}$$

141. Time of Occurrence and Propagation Velocities of the W_1 Motion. The W_2 motion generally presented a series of maxima, the 1st and 2nd being specially well defined. As will

be seen from Table XLII, the 2nd maximum was in most cases greater than the 1st. The following table gives, for each of a number of the stations where the earthquake was observed with large time-scale instruments, the epicentral distance (x), the times (t_1 and t_3) of commencement of the 1st preliminary tremor and the 3rd phase of the principal portion, and the times (t' , t'_1 and t'_2) of commencement of the W_2 motion and its 1st and 2nd maxima.

TABLE XLII. Observation of W_2 Motion.
Times of Occurrence.* [Open Seismograms.]

Place.	Epicentral Distance = x .	W_1 (Eq. Proper.)		W_2		
		Time of occurrence = t_1	Commence- ment of 3rd Ph., Princ. Portion = t_3	Commence- ment = t'	1st Maximum Phase = t'_1	2nd Maximum Phase = t'_2
{ Tokyo (EW) " (NS) " (Vertical)	51° 26'	0 59 08	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 1 & 20 & 34 \end{Bmatrix}$	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 2 & 43 & 37 \end{Bmatrix}$	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 3 & 24 & 31 \end{Bmatrix}$	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 3 & 33 & 37 \end{Bmatrix}$
			—		$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 3 & 25 & 17 \end{Bmatrix}$	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 3 & 36 & 30 \end{Bmatrix}$
			$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 1 & 20 & 31 \end{Bmatrix}$		—	$\begin{Bmatrix} \text{h} & \text{m} & \text{s} \\ 3 & 33 & 22 \end{Bmatrix}$
Osaka (EW)	48 19	0 58 51	1 19 52	—	3 22 30	$\begin{Bmatrix} 3 & 35 & 09 \\ 3 & 39 & 40 \end{Bmatrix}$
Tadotsu (EW)	47 02	0 58 49	1 18 52		3 31 22	3 36 35
{ Potsdam (EW) " (NS)	49 48	0 58 46	$\begin{Bmatrix} 1 & 17 & 29 \\ 1 & 17 & 39 \end{Bmatrix}$	3 20 31	3 25 31	—
			—	—	—	3 40 16
Triest	49 52	0 58 44	—	3 13 56	3 54 26	—
Göttingen	51 45	0 58 55	1 20 18	—	3 20 —	3 45 —
Querce	51 54	0 59 08	1 20 09	3 10 50	3 28 12	3 43 19
Birmingham (EW)	58 49	1 00 35	1 25 22	3 01 27	3 18 22	—

* t'_1 and t'_2 are respectively the times of commencement of the 1st and 2nd maxima in the W_2 motion.

Station.	Epicentral Distance = r .	W_1 (Eq. Proper).		W_2		
		Time of occurrence = t_1	Commence- ment of 3rd Ph., Princ. Portion = t_3	Commence- ment = t'	1st Maximum Phase = t'_1	2nd Maximum Phase = t'_2
Washington (NS).	105° 17'	1 ^h 08 ^m 25 ^s	1 ^h 51 ^m 16 ^s	2 ^h 27 ^m 28 ^s	2 ^h 52 ^m 30 ^s	2 ^h 58 ^m 43 ^s
{ Cheltenham (EW).	105 22	1 08 39	{ 1 49 12	—	—	{ 2 58 19
{ „ (NS).			{ 1 51 10	—	2 51 27	{ 3 02 24
{ Tacubaya (EW).	128 39	1 11 25	{ 2 01 49	2 16 41	2 43 46	—
{ „ (NS).			{ 2 09 21	—	—	2 48 25

The different places contained in the above table, with the exception of Triest, may be divided, according to the epicentral distance into two groups as follows.

TABLE XLIII. Mean Group Values of Times of Occurrence of W_2 Motion.

Group.	Epicentral Distance = x .	Time of Occurrence.			
		3rd Ph., P.P. of $W_1 = t_3$	Commence- ment of $W_2 = t'$	1st Max. of $W_2 = t'_1$	2nd Max. of $W_2 = t'_2$
(i) { Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham.	51° 18'	1 ^h 20 ^m 23 ^s	2 ^h 43 ^m 37 ^s *	3 ^h 24 ^m 21 ^s	3 ^h 38 ^m 58 ^s
(ii) { Washington, Cheltenham, Tacubaya.	113° 06'	1 54 25	2 22 05	2 49 14	2 55 09

(* Based on the Tokyo observation alone.)

Propagation Velocities, calculated by "Direct Method." Table XLIV gives the transit velocities of the W_2 motion, obtained

by the formula

$$\text{Velocity} = \frac{360^\circ - x}{t'_1 - t_0}, \text{ or } \frac{360^\circ - x}{t'_3 - t_0};$$

t_0 being the time of earthquake occurrence at the origin. The velocity relating to W_1 has been obtained in the usual way.

TABLE XLIV. Propagation Velocities, calculated by "Direct Method." [Comparison of W_1 and W_2 Velocities.]

Group.	v_3 = Velocity of the 3rd Phase of Princ. Portion, W_1 .	v'_1 = Velocity of 1st Maximum of W_2 .	v'_3 = Velocity of 2nd Maximum of W_2 .	Velocity of Commencement of W_2 .
i	km/sec. $v_3 = 3.11$	km/sec. $\frac{308^\circ 42'}{2^h 34^m 33^s} = 3.70$	km/sec. $\frac{308^\circ 42'}{2^h 49^m 10^s} = 3.38$	km/sec. $\frac{308^\circ 34'}{1^h 53^m 49^s} = 5.02$
ii	„ 3.25	$\frac{246^\circ 54'}{1^h 59^m 26^s} = 3.83$	$\frac{246^\circ 54'}{2^h 05^m 21^s} = 3.65$	$\frac{246^\circ 54'}{1^h 32^m 17^s} = 4.96$

Thus the velocity v'_3 of the 2nd, or greatest, maximum in the W_2 motion is, for Group (i), very nearly equal to the velocity v_3 of the 3rd phase of principal portion of W_1 , and it seems that these two epochs are corresponding ones; the identification of the 2nd maximum in the W_2 motion of Group (ii) being probably not correct.

Propagation Velocity, calculated by "Difference Method." Calculating, for the 2nd maximum of Group (i), the velocity by the "difference method," that is to say, by taking the time and distance differences between the minor and major arc propagations, we obtain:—

$$v'_3 = \frac{360^\circ - 2x}{t'_3 - t_3} = \frac{257^\circ 24'}{2^h 18^m 35^s} = 3.44 \text{ km/sec.}$$

This value of the velocity is not much different from that obtained by the "direct method."

142. W_2 Motion observed with Milne Horizontal Pendulums. The following table gives the results relating to the W_2 motion as registered by Milne horizontal pendulums at 11 different stations of Kew, Edinburgh, Shide, Liverpool, Paisley, San Fernando, Cape Town, Baltimore, Wellington, Alipore, and Colaba.

TABLE XLV. Observation of W_2 Motion : Times of Occurrence.
[Milne Horizontal Pendulum Seismograms.]

Station.	Epicentral Distance = δ .	W_1 (Eq. Proper).		W_2		
		Time of occurrence = t_1 .	Commence- ment of 3rd Ph., Princ. Portion = t_3 .	Commence- ment = t' .	Principal Maximum = t'_5 .	2nd Maximum = t''_6 .
		h m s	h m s	h m s	h m s	h m s
Kew.	58° 05'	1 00 12	1 23 12	—	3 36 54	—
Edinburgh.	58 48	1 00 00	1 22 36	—	—	3 46 54
Shide.	58 52	1 01 00	1 22 42 1 30 00*	3 04 36	3 20 24 3 38 42†	—
Liverpool.	59 18	1 00 36	1 23 54 1 28 54*	3 28 58	3 37 48†	—
Paisley.	59 30	1 00 00	1 23 54 1 31 12*	—	—	3 48 24
San Fernando.	66 47	1 02 30	1 27 06	—	3 30 07	—
Cape Town.	85 46	1 02 30	1 36 12	—	3 08 18	—
Baltimore.	104 47	1 10 30	1 53 06	—	3 13 30	—
Wellington.	115 45	1 09 48	1 59 54	—	2 29 18	—
Alipore (Calcutta).	13 42	0 52 00	0 55 24†	3 57 30	4 11 36	—
Colaba (Bombay).	13 28	0 53 08	0 56 39†	—	4 17 00	—

* Time of occurrence of the absolute maximum in W_1 .

† Time of occurrence of the absolute maximum in W_2 .

‡ Time of the commencement of the principal portion.

The Milne horizontal pendulum observations of the W_2 motion lead to a more uniform result than was the case with those furnished by the mechanically registering instruments. I shall next consider the records obtained at the British stations.

(1) *British Stations.* The mean results obtained from the observations at the British stations may be summarized as follows :—

- (i) *Kew, Edinburgh, Shide, Liverpool, Paisley.* 3rd phase of the principal portion of W_1 , or the earthquake proper, began at $t_s = 1^h 23^m 16^s$, the corresponding epicentral distance being $58^\circ 55'$.
- (ii) *Shide, Liverpool, Paisley.* The absolute maximum trace of W_1 on the seismograms occurred at $t_{max} = 1^h 30^m 02^s$, the corresponding distance being $59^\circ 13'$.
- (iii) *Shide.* Commencement of the W_2 motion was at $t' = 3^h 04^m 36^s$; the corresponding, or major arc, epicentral distance being $360^\circ - 58^\circ 52' = 301^\circ 08'$.
- (iv) *Shide.* A maximum occurred at $t'_1 = 3^h 20^m 24^s$. The corresponding epicentral distance $= 301^\circ 08'$, as above.
- (v) *Kew, Shide, Liverpool.* The principal maximum occurred at $t'_s = 3^h 37^m 48^s$, the corresponding major arc distance being $360^\circ - 58^\circ 45' = 301^\circ 15'$.
- (vi) *Edinburgh, Paisley.* The 2nd principal maximum occurred at $t'_0 = 3^h 47^m 39^s$, the corresponding major arc distance being $360^\circ - 59^\circ 09' = 300^\circ 51'$.

Calculating the propagation velocity for the above six cases by "direct method," that is to say, by comparing the respective time of occurrence with that at the earthquake origin, or $t_0 (= 0^h 49^m 48^s)$, we obtain :—

TABLE XLVI. Propagation Velocity of W_1 and W_2 waves,
calculated by "Direct Method."
[British Stations.]

Phase of motion.	Epicentral Distance.	Time Interval.	Velocity, calculated by "Direct Method."
(i) W_1 ... { 3rd Phase of Princ. Portion.	$x = 58^\circ 55'$	$t_5 - t_0 = 0 \text{ }^h 33 \text{ }^m 28 \text{ }^s$	$3.26 = v_5$ km/sec.
(ii) W_1 ... Absolute Max.	$x = 59 \text{ } 13$	$t_{\max} - t_0 = 0 \text{ } 40 \text{ } 14$	2.73
(iii) W_2 ... Commencement.	$360^\circ - x = 301 \text{ } 08$	$t' - t_0 = 2 \text{ } 14 \text{ } 48$	4.14
(iv) W_2 ... A max.	" = 301 08	$t'_4 - t_0 = 2 \text{ } 30 \text{ } 36$	3.71
(v) W_2 ... Princ. Max.	" = 301 15	$t'_5 - t_0 = 2 \text{ } 48 \text{ } 00$	$3.32 = v'_5$
(vi) W_2 ... 2nd " "	" = 300 51	$t'_6 - t_0 = 2 \text{ } 57 \text{ } 51$	3.14

Thus it will be seen that the velocity v'_5 of the principal maximum of the W_2 motion is very nearly equal to that of the 3rd phase of the principal portion of the W_1 motion, namely, v_5 . Assuming, therefore, (i) and (v) to be corresponding phases in the earthquake movements propagated along the minor and the major arcs, the calculation by the "difference method" gives the following result :—

$$v'_5 = \frac{360^\circ - 2x}{t'_5 - t_5} = \frac{242^\circ 30'}{2^h 14^m 32^s} = 3.34 \text{ km/sec. ;}$$

this being practically identical with that deduced by the "direct method."

(11) *San Fernando, Cape Town, Baltimore, Wellington, Ali-pore, Colaba.* The propagation velocity corresponding to the maximum in the W_2 motion at each of these stations, calculated by "direct method," is given in the following table.

TABLE XLVII. Propagation Velocity of the Maximum Phase in the W_2 Motion, calculated by "Direct Method."

[San Fernando, Cape Town, Baltimore, Wellington, Alipore, Colaba.]

Station.	Epicentral Distance.	Time Interval $=t_3' - t_0$	Velocity $v_3' = \frac{360^\circ - x}{t_3' - t_0}$
San Fernando.	$360^\circ - 66^\circ 47' = 293^\circ 13'$	$2^h 40^m 19^s$	3.39 km/sec.
Cape Town.	$360 - 85 46 = 274 14$	2 18 30	3.67
Baltimore.	$360 - 104 47 = 255 13$	2 23 42	3.29
Wellington.	$360 - 115 45 = 244 15$	1 39 30	4.55*
Alipore.	$360 - 13 42 = 346 18$	3 21 48	3.18
Colaba.	$360 - 13 28 = 346 32$	3 27 12	3.10
Mean .....	.....	.....	3.33

* This velocity is excluded in deducing the average value.

The values of the velocity v_3' given in the above table are, with the exception of that relating to Wellington, fairly uniform, indicating that the velocity in question does not vary with the distance. The average value of v_3' is

3.33 km per sec.

Next, calculating the velocity v_3' for each of the above-mentioned stations, by "difference method," namely, by comparing the time of occurrence of the 3rd phase of the principal portion of the W_1 motion with that of the principal maximum of the W_2 , we find:—

TABLE XLVIII. Propagation Velocity of the Maximum Phase in the W_1 Motion, calculated by "Difference Method."

Station.	Epicentral Distance = x	Time Difference $= t_5' - t_5$	Velocity v_5' $= \frac{360^\circ - 2x}{t_5' - t_5}$
San Fernando.	66° 47'	2 ^h 03 ^m 01 ^s	3.42 km per sec.
Cape Town.	85 46	1 32 06	3.78
Baltimore.	104 47	1 20 24	3.47
Wellington.	115 45	0 29 24	(?)
Alipore.	13 42	3 16 12	3.14
Colaba.	13 28	3 20 21	3.09
Mean. ....	.....	.....	3.38

Thus the values of the v_5' calculated by the "difference method" are, place for place, nearly identical with those calculated by the "direct method." According to the above table, the average velocity is

$$v_5' = 3.38 \text{ km per sec.},$$

which is practically identical with that obtained from Table XLVII.

143. Comparison of the Velocities of W_1 for different sets of stations. The results respecting the velocities of the W_1 motion stated in the two preceding §§ may be summarized as in the following table.

TABLE XLIX. Comparison of the Velocities of the W_1 Motion, calculated by "Direct Method."

(A) Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham. (B) Washington, Cheltenham, Tacubaya.		Phase of Motion.	British Stations.	San Fernando, Cape Town, Baltimore, Wel- lington, Alipore, Colaba.
Phase of Motion.	Velocity.		Velocity.	Velocity.
3rd Ph., P.P., W_1	$v_5 = \begin{matrix} 3.11 & (A) \\ 3.25 & (B) \end{matrix}$ km/sec.	3rd Ph., P.P., W_1	$v_5 = 3.26$ km/sec.	-- km/sec.

(A) Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham. (B) Washington, Cheltenham, Tacubaya.		Phase of Motion.	British Stations.	San Fernando, Cape Town, Baltimore, Wel- lington, Alipore, Colaba.
Phase of Motion.	Velocity.		Velocity.	Velocity.
Commencement, W_2	$\overset{\text{km/sec.}}{\left\{ \begin{array}{l} 5.02 \text{ (A)} \\ 4.96 \text{ (B)} \end{array} \right.}$	Commencement, W_2	4.14	$\overset{\text{km/sec.}}{\text{—}}$
1st Max., W_2	$\left\{ \begin{array}{l} 3.70 \text{ (A)} \\ 3.83 \text{ (B)} \end{array} \right.$	1st Max., W_2	3.71	—
2nd Max., W_2	$v'_s = 3.38 \text{ (A)}$	Principal Max., W_2	$v'_s = 3.32$	$v'_s = 3.33$
—	—	Next Max., W_2	3.14	—

From the above table, it will be seen amongst others that the principal maximum of W_2 in the Milne photograms corresponded to the 2nd (greatest) maximum in the mechanical records. The average values of the velocities v'_s and v_s , calculated both according to the “direct” and “difference” methods, are as follows :—

TABLE L. Average Values of the Velocities of W_1 and W_2 Waves.

Method of calculation.	v_s = Velocity of 3rd Ph, Principal Portion, W_1 .	v'_s = Velocity of 2nd or Principal Max., W_2 .
Direct Method.	3.21 km/sec.	3.34 km/sec.
Difference „	3.28 (§ 115)	3.39

The agreement between v_s and v'_s is very close, and we may conclude that the principal maximum in the W_2 motion approximately corresponds to the commencement of the 3rd phase of the principal portion. We have further :—

$$\left\{ \begin{array}{ll} \text{Velocity of the commencement of } W_2 = 5.0 \text{ km/sec.} \\ \text{,, ,, 1st maximum ,, = 3.75 ,,} \end{array} \right.$$

144. Amplitude and Period of Vibration in W_2 Motion.

Table LI gives the elements of motion during the successive epochs of W_2 at each of the 10 stations, as follows :—

(A) Japanese Stations.	{	Tokyo (EW).
		,, (NS).
		,, (Vertical).
		Osaka (EW).
		Tadotsu (EW).
(B) American & Mexican Stations.	{	Cheltenham (NS).
		,, (EW).
		Tacubaya (NS).
		,, (EW).
		Washington (NS).
(C) European Stations.	{	Querce (NW-SE).
		Birmingham (EW).
		Potsdam (EW).
		,, (NS).
		Göttingen.

TABLE LI. Observation
(A) Japanese

Phase of Motion.	Tokyo. EW Component.			Tokyo. NS Component.		
	Duration.	T	$2a$	Duration.	T	$2a$
	m s	sec.	mm	m s	sec.	mm
Commencement of W_2 ...	—	—	—	2 15	{ 45.0 11.9	0.1
	—	—	—	16 04	{ 19.1 12.6	—
	9 23	30.0	0.06	19 21	—	—
				4 00	—	—
1st Maximum.....	6 28	24.3	0.13	2 45	25.4	0.1
	2 38	22.1	Small	8 28	20.7	—
2nd Maximum.....	7 05	19.4	0.19	4 14	19.5	0.12
				5 13	19.5	Small
Subsequent Phases...				8 42	19.0	0.09
				1 58	17.4	Small
	43 09	17.2	Small	2 57	16.9	Small
				6 56	29.5	0.05
				4 46	20.8	Small
				39 36	26.0	..

of the W_2 Motion.
Stations.

Tokyo. Vertical Compt.			Osaka. EW Component.			Tadotsu. EW Component.		
Duration.	T	$2a$	Duration.	T	$2a$	Duration.	T	$2a$
m s	sec.	mm	m s	sec.	mm	m s	sec.	mm
—	—	—	—	—	—	—	—	—
—	—	—	1 20	—	—	—	—	—
—	—	—	5 26	25.1	Small	—	—	—
—	—	—	5 13	20.8	„	—	—	—
—	—	—	3 00	20.0	0.02	—	—	—
—	—	—	1 31	18.2	Small	—	—	—
—	—	—	5 56	18.7	0.06	5 13	—	Small
4 09	—	Small	5 00	—	—	12 25	19.5	0.05
3 15	19.5	„						
—	—	—	—	—	—	—	—	—

(B) American and

Phase of Motion.	Cheltenham. NS Compt.			Cheltenham. EW Compt.		
	Duration.	T	$2a$	Duration.	T	$2a$
Commencement of W_2	in s	sec.	mm.	in s	sec.	mm.
	—	—	—	—	—	—
1st Maximum.	5 19	29.0	0.06	—	—	—
	1 46	23.6	0.06	—	—	—
2nd Maximum.	4 46	22.0	0.19	4 36	19.7	0.28
	10 10	18.5	0.06	2 05 4 20	— 17.4	Small. 0.10

(C) European

Phase of Motion.	Querce. NW-SE Compt.			Birm'gham. EW Compt.		
	Duration.	T	$2a$	Duration.	T	$2a$
Commencement of W_2	in s	sec.	mm.	in s	sec.	mm.
	—	—	—	16 55	25.2	Small.
	5 24	15.1	0.12			
	3 46	—	Small.			
1st Maximum.	8 12	—	„	10 21	18.3	„
	6 38	18.1	0.12			
2nd Maximum.	4 16	—	Small.			
	4 13	—	„	1 10	17.5	„
	4 31	18.0	0.14			
	4 36	18.0	0.27			
	4 48	—	Small.			
	6 16	—	„			

Mexican Stations.

Tacubaya. NS Compt.			Tacubaya. EW Compt.			Washington. NS Compt.		
Duration.	T	$2a$	Duration.	T	$2a$	Duration.	T	$2a$
m s	sec.	mm.	m s	sec.	mm.	m s	sec.	mm.
—	—	—	—	—	—	10 00	16.5	Small.
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	5 30	27.0	—
—	—	—	—	—	—	—	—	—
5 00	19.4	0.48	20 35	18.0	0.10	13 00	21.9	—
15 30	16.0	0.15				5 50	13.5	—

Stations.

Potsdam. EW Compt.			Potsdam. NS Compt.			Göttingen.		
m s	sec.	mm.	m s	sec.	mm.	m s	sec.	mm.
5 00	20.0	0.13				—	25.0	—
4 44	24.4	0.18						
34 20	—	—	20 20	17.8	0.08	—	20.0	0.07

The following remarks on the amplitude and period of the W_2 motion are based on the preceding table.

Amplitude. The greatest $2a$ of 0.48 mm occurred in the NS component at Tacubaya, the dependence of the W_2 amplitude on the epicentral *major-arc* distance being as follows :—

Tacubaya.....	231° 21'	$2a = 0.48^{\text{mm}}$ (NS Compt.)
Cheltenham.....	254 38	0.28 (EW „)
Querce.....	308 06	0.27 (NW-SE „)
Tokyo.....	308 34	0.19 (EW „)

Each of the above maximum movements had period varying between 18.0 and 19.7 sec., with the mean value of 19.1 sec. The 2nd maximum was always greater than the 1st maximum, the mean ratio being nearly that of 2 : 1.

In the NS component diagram obtained at Tacubaya, the W_2 motion was very well marked, the amplitude recorded being actually greater than that of the W_1 motion, or the earthquake proper. As Tacubaya is situated nearly in the meridian passing through the earthquake origin, the NS component motion corresponds to the *longitudinal wave*, the EW component motion corresponding to the *transverse wave*. (See also § 7.) The max. $2a$'s of the W_2 motion in these two directions were in the ratio of 4.8 : 1.

Period. At the commencement of the NS component of W_2 at Tokyo there were some slow vibrations of $T = 45$ sec. The periods occurring in the 1st maximum group and the epoch immediately preceding it, which together form the 2nd phase of the principal portion, were as follows :—

$\left\{ \begin{array}{l} 30.0 \text{ sec.} \\ 29.0 \end{array} \right.$	$\left\{ \begin{array}{l} 27.0 \text{ sec.} \\ 25.4 \\ 25.2 \\ 25.1 \\ 25.0 \\ 24.4 \\ 24.3 \\ 23.6 \end{array} \right.$	$\left\{ \begin{array}{l} 22.1 \text{ sec.} \\ 20.8 \\ 20.7 \\ 20.0 \\ 20.0 \\ 19.5 \\ 19.1 \\ 18.3 \\ 18.2 \\ 18.1 \end{array} \right.$	$\left\{ \begin{array}{l} 16.5 \text{ sec.} \\ 15.1 \end{array} \right.$	$\left\{ \begin{array}{l} 12.6 \text{ sec.} \\ 11.9 \end{array} \right.$
<i>Mean, 29.5</i>			<i>Mean, 15.8</i>	<i>Mean, 12.3</i>
(Max. $2a=0.06$ mm)			(Max. $2a=0.12$ mm)	(Max. $2a=8$ small).
	<i>Mean, 25.0</i>			
	(Max. $2a=0.18$ mm)			
		<i>Mean, 19.7</i>		
		(Max. $2a=0.13$ mm)		

Thus in the 2nd phase of the principal portion there were 5 sorts of period, whose average values were respectively 29.5 ; 25.0 ; 19.7 ; 15.8 ; and 12.3 sec. ; the $2a$ enclosed in brackets giving the absolutely maximum (single component) motion for each kind of the periods. It will be observed that the vibrations of periods 25.0 and 19.7 sec. were larger and of much more frequent occurrence than those of other periods.

The periods occurring in the 2nd maximum group and the subsequent epochs, which together formed the 3rd phase of the W_2 principal portion, were as follows :—

29.5 sec.	$\left\{ \begin{array}{l} 22.0 \text{ sec.} \\ 21.9 \\ 20.8 \\ 20.0 \\ 20.0 \\ 19.7 \\ 19.5 \\ 19.5 \\ 19.5 \\ 19.4 \\ 19.4 \\ 19.0 \end{array} \right.$	18.7 sec.	13.5 sec.
(Max. $2a=0.05$ mm)		18.5	(Small.)
		18.0	
		18.0	
		18.0	
		17.8	
		17.5	
		17.4	
		17.4	
		17.2	
		16.9	
		16.0	
		<i>Mean, 18.9</i> sec.	
		(Max. $2a=0.48$ mm)	

Thus in the phase under consideration, the period varied, with two exceptions, between 16.0 and 22.0 sec., giving a mean value of 18.9 sec. The vibrations of this sort are evidently the same as those in the previous phase whose mean period was 19.7 sec.

Again, comparing together the three tables (A), (B), and (C), we see that on the whole slower vibrations occurred first, the approximate order of succession of the principal different periods being as follows :—(i) 45.0 ; (ii) 29.5 ; (iii) 25.0 ; (iv) 19.7—18.9 sec. This occurrence of periods in the descending order of magnitude (length) is a characteristic of the principal portion of the earthquake motion.

Average Periods. The mean values of the various periods of vibration in the W_2 motion recorded at the different stations are collected in the following table, those of more frequent occurrence being printed in thick characters.

TABLE LII. Average Values of the Periods in W_2 Motion.

	sec.	sec.	sec.	sec.	sec.	sec.	sec.
Tokyo.	12.3	—	19.4	—	25.1	29.8	45.0
Osaka.	—	—	19.6	—	25.1	—	—
Tadotsu.	—	—	19.5	—	—	—	—
Göttingen.	—	—	20.0	—	25.0	—	—
Potsdam.	—	17.2	20.0	—	24.4	—	—
Quebec.	—	15.1	18.0	—	—	—	—
Birmingham.	—	17.5	18.3	—	25.2	—	—
Washington.	13.5	16.5	—	21.9	—	27.0	—
Cheltenham.	—	—	18.6	22.8	—	29.0	—
Tacubaya.	—	—	18.2	—	—	—	—
Mean.	12.7	16.6	19.1	22.5	25.0	28.9	45.0

Thus it will be observed that the period most frequently occurring is 19.1 sec., being almost universally indicated at the different places. The 2nd maximum group of the W_2 motion, in which the above-mentioned period predominated, may be taken as corresponding to the 3rd phase of the principal portion of the W_1 motion, or earthquake proper.

REPETITION OF THE EARTHQUAKE MOTION FIRST PROPAGATED ALONG THE MINOR ARC.

145. Observation of W_3 Motion. TABLE LIII gives the times of occurrence of the W_3 wave or the repetition of the earthquake motion first propagated along the minor arc, observed more or less clearly at the 7 stations of Tokyo, Osaka, Tadotsu, Cheltenham, Shide, Wellington, and Colaba.

TABLE LIII. Observation of W_3 Motion : Times of Occurrence.

Station.	Epicentral Distance = x .	W_1 Motion (Eqke. Proper)		Commencement of $W_3 = t_3$.
		Time of occurrence = t_1	Commencement of 3rd Phase, Princ. Port. = t_3	
Tokyo (EW).	51° 26'	^h 0 ^m 59 ^s 08	^h 1 ^m 22 ^s 26	^h 4 ^m 24 ^s 08
Osaka (EW).	48 19	0 58 51	1 19 52	4 34 59
Tadotsu (EW).	47 02	0 58 49	1 18 52	4 24 35
Cheltenham (NS).	105 22	1 08 39	1 49 12	5 22 04
Shide.	58 52	1 01 00	1 22 42	4 34 45*
Wellington.	115 45	1 09 48	1 59 54	4 36 36
Colaba.	13 28	0 53 08	0 56 39†	4 24 00

* Measured from the records given by the two pendulums B and C.

† Commencement of the principal portion.

The propagation velocity of the W_3 motion may be calculated by the "direct method" according to the formula

$$\text{Velocity} = \frac{360^\circ + x}{t''_5 - t_0},$$

where t'' denotes the time of occurrence of W_3 . We obtain the following results:—

TABLE LIV. Velocity of the W_3 Motion,
calculated by "Direct Method."

Station.	Epicentral Distance. $= 360^\circ + x.$	Time Difference $= t'' - t_0$	Velocity. "Direct Method."
		^h ^m ^s	^{km/sec.}
Tokyo.	411° 26'	3 33 20	3.57
Osaka.	408 19	3 45 11	3.36
Tadotsu.	407 02	3 34 47	3.61
Cheltenham.	465 22	4 32 16	3.17
Shide.	418 52	3 44 57	3.46
Wellington.	475 45	3 46 48	3.89
Colaba.	373 28	3 34 12	3.23
Mean .....	.....	.....	3.40

The identification of the W_3 motion was extremely difficult, and the results above obtained are to be regarded as, at the best, only gross approximations. The average value of the velocity is **3.40** km per sec.,* which is nearly equal to that of the 3rd phase of the principal portion of W_1 . Assuming, there-

* As will be seen from the value of $(t'' - t_5)$ given below, the identification of W_3 for Wellington is probably not quite correct. The velocity for this station has therefore been excluded in deducing the average.

fore the W_3 motion to correspond to the 3rd phase of the principal portion, we obtain, from Table LIII:—

Tokyo.	$t_5'' - t_3 =$	^h 3	^m 01	^s 42
Osaka.		3	15	07
Tadotsu.		3	05	43
Cheltenham.		3	32	52
Slide.		3	12	05
Wellington.		2	36	42*
Colaba.		3	27	21
Mean		3	15	48

The mean time difference of ^h3 ^m15 ^s48, deduced by excluding the value for Wellington (marked with an *asterisk*), is the time interval taken by the earthquake motion in making one complete circuit round the earth and does not depend on the epicentral distance x . We have:—

$$\text{Velocity} = \frac{\text{Earth's Circumference}}{t_5'' - t_3} = \frac{360^\circ}{3^h 15^m 48^s} = 3.40 \text{ km/sec.}$$

(See also the *Publications*, No. 13).

Periods of Vibration. The periods of vibration occurring in the W_3 motion were as follows.

	^{sec.}	^{sec.}	^{sec.}
Tokyo.	20.5	—	44.0
Osaka.	18.5	—	—
Tadotsu.	—	36.3	—
Cheltenham.	18.2	—	—
Mean.	19.1	36.3	44.0

The principal period of vibration in W_3 is the same as that occurring in the most active part of the W_2 motion.

GENERAL REMARKS ON THE PROPAGATION VELOCITIES.

146. Velocities calculated by "Direct Method." The mean values of the different velocities calculated by the "direct method" are as follows.

TABLE LV. Mean values of the Velocities.
"Direct Method."

Phase of motion.	Velocity.	Limits of Epicentral Distance.	Mean Distance.
1st Prel. Tremor.	$v_1 = \overset{\text{km. sec.}}{10.52}$	50° —121°	76°
2nd „ „	$v_2 = 5.63$	40 —115 45'	61 36'
1st Phase, Princ. Port.	$v_3 = 4.07$	47 —128 47	70 52
3rd „ „ „	$v_3 = 3.11$	39 27'—128 47	{ Practically independent of the distance x .
Commencement, W_2 .	5.0		
1st Maximum, W_2 .	$v_5 = 3.75$		
Principal max., W_3 .	$v_5' = 3.34$		
W_3	$v_5'' = 3.40$		

The four velocities v_1 , v_2 , v_3 , and v_5 are in the ratios of 100: 53.5 : 38.7 : 29.6. The velocity of the principal maximum of W_2 and that of W_3 are approximately equal to v_3 . The 1st maximum of W_2 seems to correspond to the 2nd phase of the principal portion, and the earliest recorded commencement of the major are propagation to some part of the 2nd preliminary tremor.

The average values of the velocities for the stations in Middle Europe and Japan are as follows:—

$$\left\{ \begin{array}{ll} v_1 = 10.38 \text{ km/sec.} & (22 \text{ stations, mean } x = 50^\circ 24') \\ v_2 = 5.73 & \text{„ } (20 \text{ „ „ „ } = 50 \text{ } 12) \\ v_3 = 3.92 & \text{„ } (7 \text{ „ „ „ } = 50 \text{ } 17) \\ v_5 = 3.02 & \text{„ } (8 \text{ „ „ „ } = 50 \text{ } 34) \end{array} \right.$$

These 4 velocities are in the ratios of 100 : 55 : 38 : 29.

147. Velocities calculated by "Difference Method." The mean values of the different velocities calculated by the "difference method" are as follows.

TABLE LVI. Mean Values of the Velocities.
"Difference Method."

Phase of motion.	Velocity.	Limits of Epicentral Distance.
1st Preliminary Tremor.	$v_1 = \overset{\text{km/sec.}}{\mathbf{11.36}}$	27° 57' — 121° 16'
2nd " "	$v_2 = \mathbf{6.46}$	27 42 — 128 47
1st Phase, Princ. Portion.	$v_3 = \mathbf{4.70}$	39 27 — 128 47
3rd " , " "	$v_5 = \mathbf{3.28}$	39 27 — 128 47
Principal Maximum, W_2 .	$v_5' = \mathbf{3.39}$	
W_3	$v_5'' = \mathbf{3.40}$	

The 4 velocities v_1 , v_2 , v_3 , and v_5 are in the ratios of 100 : 56.9 : 41.4 : 28.9; the mutual relations being nearly the same as in the cases of the velocities calculated by the "direct method." The agreement of the velocities of W_2 (principal max.) and W_3 with that of the 3rd phase of the principal portion is here closer than in the case of the "direct method" calculation.

Comparisons of the velocities calculated by "direct" and "difference" methods. Comparing the mean values of the different velocities calculated according to the "direct method" with those calculated according to the "difference method," as given in Tables LV and LVI, we obtain :—

$$\left\{ \begin{array}{l} v_1 \text{ (Difference Method)} - v_1 \text{ (Direct Method)} = 0.84 \text{ km/sec.} \\ v_2 \text{ (")} - v_2 \text{ (")} = 0.83 \\ v_3 \text{ (")} - v_3 \text{ (")} = 0.63 \\ v_5 \text{ (")} - v_5 \text{ (")} = 0.17 \\ v_5' \text{ (")} - v_5' \text{ (")} = 0.05 \\ v_5'' \text{ (")} - v_5'' \text{ (")} = 0.00 \end{array} \right.$$

Thus it will be seen that the velocities v_1 , v_2 , and v_3 , calculated by the "difference method" were each greater 0.63 to 0.84 km per sec., than those calculated by the "direct method." The discrepancy is, however, very small or *nil* for the velocities v_5 , v_5' , and v_5'' . This fact seems to give support to the view that the vibrations composing the 1st and 2nd preliminary tremors, as well as the earlier part of the principal portion, are propagated some considerable depth below the surface, the length of the actual path for each of these sets of waves materially differing from that of the areal epicentral distance.

148. Mutual Relations of the different Velocities. Assuming the durations of the first 7 successive sections of the earthquake motion to be, as stated in § 8, in the ratios of 100 : 95 : 79 (1st and 2nd phases of principal portion taken together) : 91 : 95 : 95, we have the following general relations among the different velocities* :—

$$\begin{array}{ll} \frac{1}{v_2} = \frac{1}{v_1} + \frac{y_1}{x}; & \frac{1}{v_6} = \frac{1}{v_5} + \frac{91 y_1}{100 x}; \\ \frac{1}{v_3} = \frac{1}{v_2} + \frac{95 y_1}{100 x}; & \frac{1}{v_7} = \frac{1}{v_6} + \frac{95 y_1}{100 x}; \\ \frac{1}{v_5} = \frac{1}{v_3} + \frac{79 y_1}{100 x}; & \frac{1}{v_8} = \frac{1}{v_7} + \frac{95 y_1}{100 x}; \end{array}$$

x being the epicentral distance of a given station, and y_1 the

* See the *Publications*, No. 5 and No. 13.

duration of the 1st preliminary tremor at the latter. The quotient y_1/x is to be determined from some of the equations (1) to (4) in § 121, and the equation (7) in § 123. As an example, let us apply the above relations to the velocities of the Kangra earthquake calculated by the "direct method" for the stations in Middle Europe and Japan, (§ 146); the mean value of the x being $50^{\circ} 22'$, and the quantity y_1/x being given by equation (1) of § 121. Assuming $v_1=10.38$ km/sec., we have :—

<i>Actual Value.</i>	<i>Calculated Value.</i>
$v_1=10.38$ km/sec.	10.38 km/sec.
$v_2= 5.73$	5.6
$v_3= 3.92$	3.9
$v_4= 3.02$	3.1

The agreement between the actual and calculated values is fairly good.

Ratio of $v_1:v_2$. The ratios of the 4 velocities v_1, v_2, v_3 , and v_4 , are, according to the two preceding §§, as follows :—

(i) "Direct Method." 100 : 53.5 : 38.7 : 29.6

(ii) "Difference Method." . . 100 : 56.9 : 41.4 : 28.9

Mean **100 : 55.2 : 40.1 : 29.3**

Thus, amongst others, the mean ratio of $v_1:v_2$ is 100 : 55.2. Now, the equation* for determining the time (t_0) of earthquake occurrence at the origin, from the duration (y_1) of the 1st preliminary tremor, is

$$t_0 = t_1 - \frac{y_1}{\frac{v_1}{v_2} - 1} \dots \dots \dots (1)$$

Putting the mean ratio of $v_1:v_2$ above obtained, the equation becomes :—

* The *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 1.

$$t_0 = t_1 - 1.232 y_1 \dots \dots (2)$$

For the purpose of practical application, however, it seems better to adopt the ratio of $v_1 : v_2$ obtained by the "direct method"; the formula then becomes

$$t_0 = t_1 - 1.151 y_1 \dots \dots (3)$$

Equation (3) does not much differ from one previously given.

149. *Remarks on the Methods of Velocity Calculation.*

In all the velocity calculations by the "direct method" given in the preceding Chapters, the times of occurrence of the different phases of the earthquake motion at a given station have been compared with the time (t_0) at the origin of disturbance. This is equivalent to assuming that at the latter there existed no preliminary tremor; in other words, that the various sets of vibrations composing the seismic motion were generated simultaneously at the centre. I believe this supposition is generally legitimate, although there is possibility, especially in cases of large earthquakes, of slight premonitory shakings apart from the usual preliminary tremors.

Chapter X. Miscellaneous Remarks.

150. *Notes on the Tokgo Observations.* The following remarks on the Tokyo observations are based on the analysis of the seismograms of the Kangra earthquake given in §§ 13 to 21.

151. *Small movements of Sensible or Macro-seismic Character.* The Hitotsubashi diagram furnished by a horizontal pendulum of 8 times magnification indicated in the 1st preliminary tremor

small vibrations, whose average period was 0.71 sec. These movements were evidently of the character of macro-seismic or sensible motion, their period being nearly equal to that most frequently occurring in ordinary earthquake shocks observed at Hitotsubashi.* The occurrence in distant earthquakes of quick vibrations, whose period is about 1 sec., is not very rare† From the observations like the above we may conclude :

(i) That *a great earthquake disturbance may give rise to small vibrations of macro-seismic character at a considerably distant place, especially when the soil at the latter is soft.* It is a movement of this sort which starts the electric contact-maker of an ordinary Ewing or Gray-Milne seismograph at a far-off station; those large vibrations in the 2nd preliminary tremor or the different phases of the principal portion are quite inadequate to affect a macro-seismograph on account of the length of the period, their acceleration of motion of the earth's particle being a very small quantity.

(ii) That *the principal period of the macro-seismic vibration at Hitotsubashi is practically constant and independent of the earthquake cause or of the epicentral distance.* This inference, which probably holds good for any other place where the ground is soft, may be accounted for by assuming that the earthquake vibrations at a place are essentially composed of the proper oscillations of the ground characteristic to the region in question;‡ well defined vibrations at the commencement of the different phases of the motion being excepted.

152. Pulsatory Oscillations. Both before and after the Kangra earthquake there existed very small pulsatory oscillations, which

* See the *Publications*, No. 11 and No. 13.

† The *Publications*, No. 13.

‡ See the *Publications*, No. 11 and No. 13.

were clearly recorded by the tromometers, and which belonged to the Q_1 class motion,* their average period being 4.1 sec. By the way, it may be remarked that the period of these pulsatory oscillations was identical at the University Compound (Hongo) and at the Central Meteorological Observatory, in spite of a mutual distance of 3 km, and of an entire difference in the nature of the grounds, between the two places.

Turning our attention to the P_1 motion, we find from §§ 14 to 20, that the records furnished by the different instruments were as follows:—

		<i>T</i>	Max. <i>2a</i>
EWCOMPONENT.	§ (14): 1st Prel. Tremor, . . .	4.6 sec. ;	0.20 mm
	„ (20): „	4.4	0.25
	„ (21): „	4.4	0.17
	„ (18): „	4.6	0.35
	„ (20): 2nd Prel. Tremor, . . .	4.8	0.21
	<i>Mean</i>	4.6 sec.	0.24 mm
NS COMPONENT	: 1st Prel. Tremor, . . .	5.2 „	0.14 „
VERTICAL COMPT	: „ „ „	4.2	0.71 (?)

Comparing, for the EW component, the pulsatory oscillation (Q_1) with the earthquake vibration (P_1), we see that the amplitude of the latter was some 20 times that of the former; the periods of the two sets of motion being, however, nearly equal to one another. This result seems to give support to the theory advanced by me some years ago that the pulsatory oscillations (Q_1 and Q_2) and the earthquake vibrations (P_1 and P_2) are essentially alike in nature, and that the latter consist in the amplification of the former, which always exist more or less at, and characterize, a given district.† For the sake of reference, I give next the periods of the pulsatory

* See the *Publications*, No. 13.

† See the *Publications*, No. 13.

oscillations on Mount Tsukuba (in the province of Hitachi, Japan), at Ishinomaki (province of Rikuzen), Osaka, and Taito (Formosa):

- | | |
|--|---|
| (i) Mount Tsukuba* (Province of Hitachi, Japan). | Q_1 : T =about 4 sec. |
| (ii) Ishinomaki. | Q_1 : T =5.2 sec., $2a$ =0.05 mm. |
| (iii) Taito (Formosa). | Q_1 : $\begin{cases} T=5.6 & \text{,,} & 2a=0.2 \text{ mm} \\ T=4.7 & \text{,,} & 2a<0.2 \text{ mm.} \end{cases}$ |
| (iv) Osaka. | Q_1 : T =5.0 sec. |

The pulsatory oscillation indicated on the Batavia photogram (§ 47) had a period of 7.6 sec. and may correspond to Q_2 .

153. *On the Comparison of Diagrams furnished by different instruments; existence of P_2 vibrations in the 2nd Preliminary Tremor and the Principal Portion.*

As will be seen from §§ 14 and 20, the diagram given by the long-period horizontal pendulum is materially different from that given by the tromometer. Thus, the former diagram shows, in the 2nd preliminary tremor most prominently 4 sets of slow vibrations of T respectively=49.7 sec., 37.7 sec., 86.0 sec., and 26.5 sec.; the P_1 and P_2 vibrations being altogether absent or only insignificantly shown. On the other hand, the 2nd preliminary tremor in the tromometer diagram is entirely made up of 3 sets of comparatively quick movements, namely, P_1 , P_2 , and $P_{2,3}$ vibrations. Again, the long-period pendulum record indicated, in the 1st and 2nd phases of the principal portion, prominent vibrations of T of 27.6 to 59.0 sec.; $P_{2,3}$ vibrations being only slightly shown. In the corresponding part of the tromometer record, however, P_2 vibrations were indicated nearly to the same extent as other slower movements, whose period varied between 16.8 sec. and about 53 sec.

* The observation made with a horizontal pendulum tromometer by His Imperial Highness Prince Yamashina at his Observatory on Mount Tsukuba has proved that the pulsatory oscillation exists, though slightly, also on solid mountain tops.

The principal cause of the great dissimilarity between the records furnished by the two instruments was evidently in the difference in the lengths of the periods of natural oscillation of the two pendulums.*

The real amplitude of the slow vibrations in the 2nd preliminary tremor and the principal portion seems, in great earthquakes, to be considerable and much greater than is shown in most seismograms; the friction between the different parts of the seismograph reducing, even when the *steady mass* has a long oscillation period, the *recorded* range of such a motion more or less.

One notable fact demonstrated by the tromometer record is that the P_2 vibrations were not confined to the 1st preliminary tremor, but also occurred prominently in the 2nd preliminary tremor and in the 1st and 2nd phases of the principal portion. It is highly probable that the P_2 vibrations exist throughout the principal portion of every large earthquake motion. (See also § 126.)

The question of the existence of P_2 vibrations in the principal portion is very important in connection with the discussion of the different periods occurring in the earthquake motion. As I have pointed out in the *Publications*, No. 13,† the principal period of vibration occurring in the *preliminary tremors* and the *end portion* is P_2 (some times P_1), and it would be strange, if similar movements did not occur in the intermediate phases, namely, the *principal portion*; it being quite natural to assume some existence throughout the earthquake motion of the P_1 and P_2 vibrations, which are identical to the proper Q_1 and Q_2 oscillations of the ground.

* See the *Publications*, No. 23

† Published in 1901.

154. Direction of Motion. Confining our attention to the EW component, we see, from the analysis of the record given by the long-period instrument (§ 14), that the 1st displacement of the initial slow vibration of each of the two preliminary tremors was directed towards W; the 1st motion of the initial (P_1) vibration of the 1st preliminary tremor being, according to the tromometer record (§ 20), also directed towards W. Similar directional tendency of motion was shown more clearly in the 3rd phase of the principal portion recorded by the latter instrument, where there were a series of maximum groups, of which 4 well defined ones have been described in § 20. The amplitudes of the successive displacements of vibrations composing one of these groups were, on the average, in the following relative ratios :—

1st displ.	2nd displ.	3rd displ.	4th displ.	5th displ.	6th displ.
{ (E)	(W)	(E)	(W)	(E)	(W)
{ 1.00	1.84	3.31	6.22	6.90	5.60

It will be thus seen that the 1st, 2nd, and 3rd displacements, were directed towards E, W, and E, respectively; it being the 4th and westward motion which constitutes the first and sudden large displacement.

In the NS component diagram (§ 15), the 1st displacement of the well-defined slow vibration at the commencement of the 1st preliminary tremor was directed towards N; the very initial motion of quick movements mixed with the above being also directed towards N.

155. Similarity with the diagrams of the Alaska earthquakes. The EW component Tokyo diagram of the Kangra earthquake (Pl. I, the *Publications*, No. 23) is on the whole somewhat similar to those of the Alaska earthquakes of 1899 and

1900*; the movements at the commencement of the 2nd preliminary tremor being specially alike each other. This is evidently the result due to a sort of symmetry of the positions of the origins of the two sets of earthquakes with respect to the meridian (or prime vertical) of Tokyo; the positions of the centres in question relative to the latter place being as follows:—

	Epicentral Distance of Tokyo.	Azimuth of Eqke. Origin.
Kangra Eqke.	51° 26'	W 75° 05' 36" (from N)
Alaska Eqkes.	55° ca.	E 40° ca.

156. *Time Difference between Tokyo and Osaka.* The times of commencement of the successive phases of motion at Tokyo and Osaka were as follows:—

TABLE LVII. Time Difference between Tokyo and Osaka.

Phase of motion. (Commencement)	Tokyo.	Osaka.	Time Difference. (Tokyo—Osaka.)
(i) 1st Prel. Tremor.	0 ^h 59 ^m 08 ^s	0 ^h 58 ^m 51 ^s	+17 ^{sec.}
(ii) 2nd „ „	1 06 46	1 06 03	43
(iii) 1st Phase, Princ. Portion.	1 14 24	1 13 15	69
(iv) 3rd „ „ „	1 22 34	1 20 09	145
(v) 4th „ „ „	1 33 49	1 30 05	224
(vi) 5th „ „ „	1 42 04	1 38 05	239
(vii) Max. Mot. in W_2 .	3 39 07	3 40 56	−109

The arcual epicentral distances of Tokyo and Osaka are 51° 26' and 48° 19' respectively, and consequently the time differences between these two places (Tokyo—Osaka) were positive for the different phases of W_1 or the earthquake proper, but negative for

* See Pls. VII and VIII of the *Publications*, No. 5, and Pl. XXXVI of the *Publications*, No. 21.

the W_2 motion. It is difficult to determine exactly the instants of commencement of some of the different phases of motion, and the above time differences are only rough values, with the exception of two well defined cases of the 2nd and the last; which two relate respectively to the commencements of the 2nd preliminary tremor and the maximum vibration in the W_2 motion. Calculating from these two cases the transit velocities, we obtain the following approximate results :—

$$\left\{ \begin{array}{l} v_2 = \frac{51^\circ 26' - 48^\circ 19'}{43^{\text{sec.}}} = 8.0 \text{ km/sec.;} \\ v'_5 = \frac{51^\circ 26' - 48^\circ 19'}{109^{\text{sec}}} = 3.18 \quad \text{,,} \quad . \end{array} \right.$$

(See also Chapter IX.)

157. Comparison of individual vibrations in the Tokyo and Osaka Seismograms. Some of the individual vibrations in the 1st and 2nd preliminary tremors can be identified with fair accuracy in the Tokyo and Osaka EW component diagrams; the times of occurrence of the corresponding movements in the two records, denoted by similar letters, $a, b, c, d, \dots, s, t, u$, being as in the following table. (See Pls. I and VI, the *Publications*, No. 23.)

TABLE LVIII. Comparison of the Different Vibrations in the Tokyo and Osaka EW Diagrams.

Vibration.	Tokyo.	Osaka.	Time Difference. (Tokyo-Osaka).
$\left\{ \begin{array}{l} a \\ b \\ c \end{array} \right.$	$\begin{array}{l} 0^{\text{h}} \ 59^{\text{m}} \ 08^{\text{s}} \\ 0 \ 59 \ 36 \\ 1 \ 00 \ 05 \end{array}$	$\begin{array}{l} 0^{\text{h}} \ 58^{\text{m}} \ 51^{\text{s}} \\ 0 \ 59 \ 16 \\ 0 \ 59 \ 40 \end{array}$	$\begin{array}{l} 17^{\text{sec.}} \\ 20 \\ 25 \end{array}$

Vibration.		Tokyo.	Ōsaka.	Time Difference. (Tokyo-Ōsaka).
1st Prel. Tremor.	<i>d</i>	1 ^h 00 ^m 28 ^s	0 ^h 59 ^m 56 ^s	32 ^{sec.}
	<i>e</i>	1 01 24	1 01 03	21
	<i>f</i>	1 01 36	1 01 12	24
	<i>g</i>	1 02 23	1 02 02	21
	<i>h</i>	1 06 38	1 06 03	35
2nd Prel. Tremor.	<i>i</i>	1 06 46	1 06 08	38
	<i>j</i>	1 07 05	1 06 18	47
	<i>k</i>	1 07 23	1 06 35	48
	<i>l</i>	1 07 55	1 06 50	65
	<i>m</i>	1 08 53	1 07 58	55
	<i>n</i>	1 09 49	1 08 49	60
	<i>o</i>	1 10 48	1 09 58	50
	<i>p</i>	1 11 07	1 10 19	48
	<i>q</i>	1 11 45	1 10 42	63
	<i>r</i>	1 12 34	1 11 25	69
	<i>s</i>	1 13 07	1 11 53	74
	<i>t</i>	1 13 40	1 12 23	77
	<i>u</i>	1 14 24	1 13 15	69

The identifications given in the above table indicate, on the whole, a gradual separation of the successive vibrations at the rate of about 3.93 sec. for 1 minute of the duration.

158. Kew, Paisley, and San Fernando Records. Some of the maximum movements may be identified in the seismograms at San Fernando, Kew and Paisley; these are marked by the letters *a, b, . . . m, n*. But the times of occurrence of these maxima at the above-mentioned 3 stations are, as given in the following table,

not perfectly in accordance to the respective epicentral distances, due probably to an inaccuracy in the identifications. We can see, however, from examples like these, that the teleseismograms obtained at neighbouring places ought to be nearly identical, if not much interfered by the proper instrumental oscillations.

Max.	San Fernando.	Paisley.	Kew.	Max.	San Fernando.	Paisley.	Kew.
a_1	1 ^h 16.0 ^m	1 ^h 13.2 ^m	1 ^h — ^m	g	1 ^h 51.7 ^m	1 ^h 48.6 ^m	1 ^h 45.7 ^m
a'	1 20.8	1 16.3	—	h	1 57.8	1 54.6	1 —
a	1 29.0	1 26.7	1 25.4	i	2 1.5	1 59.0	1 53.0
b'	1 31.7	1 29.0	1 27.3	j	2 7.0	2 5.8	1 56.5
b	1 33.8	1 31.4	1 28.9	k	2 14.5	2 12.8	2 7.6
c	1 36.7	1 34.4	1 32.6	l	2 20.4	2 17.9	2 13.7
d	1 39.0	1 36.4	1 35.5	m	2 27.6	2 30.4	2 22.0
e	1 42.5	1 39.8	1 37.7	n	2 35.7	2 38.5	2 31.0
f	1 45.5	1 43.9	1 40.4				

159. Vibrations of Short Periods. The periods shorter than P_1 observed at some of the different stations were as follows:—

- (i) Hitotsubashi (Tokyo): $T=0.71$ sec.
- (ii) Hongō : „ =2.2 „
- (iii) Taihoku : „ =1.07 „ ; $T=2.1$ sec.
- (iv) Batavia : „ =1.4 „
- (v) Manila : „ =2.6 „ (pendulum oscillation.)
- (vi) Göttingen : „ =2.2 „
- (vii) Upsala : „ =2.5 „

The vibrations corresponding to these periods were always very small. As already stated in § 150, (i) is the same as the period of the motion on the occasion of ordinary shocks observed in the

low soft part of Tokyo. The periods of 1.07 sec. at Taihoku (iii), and of 1.4 sec. at Batavia (iv), also characterize the movements of macroseismic nature. The semi-macroseismic periods observed at Hongō (ii), Taihoku (iii), Göttingen (vi), and Upsala (vii), varied between 2.1 and 2.5 sec., giving the average value of $2\frac{1}{2}$ sec. This is approximately equivalent to $\frac{1}{2}P_1$.

160. Durations of the Successive Sections of the Earthquake Motion. Let the durations of the 1st and 2nd preliminary tremors, and the 1st, 2nd, 3rd, and 4th phases of the principal portion be respectively denoted by y_1 , y_2 , $y_{3,4}$, y_5 , and y_6 ; the 1st and 2nd phases of the latter portion being taken together. The values of the y 's observed at the 15 different stations on the occasion of the Kangra earthquake are given in Table LIX; the stations being divided into two groups (I) and (II), according to their epicentral distances. An *asterisk* suffixed to the name of a station signifies that the respective durations have been deduced by taking the means from more than one seismogram.

TABLE LIX. Durations of the Successive Sections of the Earthquake Motion.

Station.	1st Prel. Tremor.	2nd Prel. Tremor.	1st & 2nd Ph. Princ. Port.	3rd Phase, Princ. Port.	4th Phase, Princ. Port.
	(y_1)	(y_2)	($y_{3,4}$)	(y_5)	(y_6)
I (Tokyo.* Osaka. Tadotsu. Taihoku. Taichu. Birmingham.)	7 ^m 17 ^s *	7 ^m 42 ^s *	7 ^m 19 ^s *	8 ^m 50 ^s *	— ^s *
	7 12	6 55	6 54	9 56	8 00
	7 00	7 42	5 21	6 30	6 00
	6 06	5 25	4 35	5 30	—
	6 14	5 10	4 50	5 40	—
	8 21	7 37	8 49	9 30	6 21

Station.	1st Prel. Tremor. (y_1)	2nd Prel. Tremor. (y_2)	1st & 2nd Ph., Princ. Port. ($y_{3,4}$)	3rd Phase, Princ. Port. (y_5)	4th Phase, Princ. Port. (y_6)
{ Quarto-Castello, Querce, Ximeniano.	7 ^m 15 ^s	(15 ^m 09 ^s)		8 ^m 15 ^s	— ^{m s}
Göttingen.	7 17	7 40 ^{m s}	6 35 ^{m s}	5 55	5 35
Leipzig.*	7 06	7 37	6 28	7 45	5 23
Manila.	6 38	5 10	6 10	—	—
Mean.	7 03	6 56	6 26	7 41	6 07
II {	Washington.	15 02	12 09	22 50	—
	Cheltenham.*	14 44	12 15	11 31	11 20
	Tacubaya.	16 38	15 42	14 52	—
	Mean.	15 17	13 05	15 11	11 20

Thus it will be seen that the durations of the successive sections of the earthquake motion are, for each group of the stations, roughly equal to one another. The relative durations expressed in percentage numbers are given in the following table; the means deduced from the two groups (I) and (II), supposing their weights to be 2 : 1, being $y_1=100$, $y_2=94$, $y_{3,4}=95$, $y_5=106$, $y_6=83$.

TABLE LX. Relative Durations of the Successive Sections of the Teleseismic Motion.

Group.	y_1	y_2	$y_{3,4}$	y_5	y_6
I.	100	98	91	109	87
II.	100	86	103	99	74
Mean.	100	94	95	106	83
Table III, § 8.	100	95	79	91	95
General average.	100	95	87	99	89

grams at Tokyo and Osaka were so far alike, that the individual corresponding vibrations have in many cases, been identified. Conversely, it may be supposed that earthquakes originating at neighbouring centres would give, in general, similar diagrams at a given observing station. This has been verified in the cases of many teleseismic, as well as, macroseismic, or sensible earthquake motion observed in Tokyo.*

Quick Vibrations. Small quick vibrations of macroseismic nature occurring in the teleseismic disturbance seem, unlike the slow movements, to depend on the nature of the ground, and are probably to be regarded as the secondary effect of the microseismic or pulsatory movements.

162. Nature of the Two Preliminary Tremors. It is generally recognized that the 1st and 2nd preliminary tremors of the *teleseismic motion* belong to the "longitudinal" and the "transverse" waves respectively. It is, however, not clear why the transverse vibration is in these cases always much greater than the longitudinal. The diagrams of the Kangra earthquake also indicate, in general, the same relation of the two preliminary tremors.

(i) *Mexico and America.* According to Table II (§ 8), Tacubaya is almost due north of the origin, and from the seismograms (Pl. X, the *Publications*, No. 23) we see that in the NS or longitudinal component, the vibrations in the 1st preliminary tremor were more distinct than in the EW or transverse component. The movements of the NS component were, however, less prominent than those of the EW, in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion; on the contrary,

* See the *Publications*, No. 21.

the NS component being much larger than the EW in the 3rd and 4th phases of principal portion and in the W_2 motion.

The Cheltenham records do not markedly indicate the directional peculiarity, except that the 3rd phase of the principal portion is much greater in the NS (longitudinal) component than in the EW (transverse).

(ii) *Central Europe.* Of the Central Europe stations, whose EW and NS components approximately or very nearly corresponded to the longitudinal and transverse vibrations, Potsdam and Göttingen show very clearly the following characteristics:—

- (a) In the 1st Preliminary Tremor, EW motion was much greater than the NS motion.
- (b) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.
- (c) In the 3rd Phase of the Principal Portion, the EW motion was greater than the NS motion.
- (d) W_2 . . . EW motion was much greater than NS motion.

Again, the 4 other stations of Quarto-Castello, Leipzig, O'Gyalla, and Ischia,* show the following characteristics:—

- (a) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.
- (b) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.
- (c) The NS Component motion was, except for Ischia, on the whole greater than the EW component motion.
- (d) 3rd and 4th Phases of Principal Portion At Ischia, the EW motion was much greater than the NS motion.

* The copies of the seismograms obtained at these 4 stations were not long enough to enable me to identify the W_2 motion.

(iii) *Japan*. The seismograms obtained at Tokyo, Osaka and Kobe, whose EW and NS components approximately correspond to the longitudinal and transverse vibrations respectively, show the following characteristics :—

- (a) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.
- (b) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was smaller than NS motion.
- (c) In the 3rd and 4th Phases, Principal Portion, the EW motion was greater than the NS motion.
- (d) W_2 EW motion was greater than NS motion.

Summary. Although the interference of the proper instrumental oscillations makes it often very difficult to form a correct comparison of the vibration amplitudes between the different seismograms, we may conclude from what was stated above provisionally as follows:—In the preliminary tremor and the 3rd and 4th phases of the principal portion, as well as the principal part of the W_2 motion, the longitudinal vibrations predominate more than the transverse; while in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion, the transverse vibrations predominate more than the longitudinal.* The difference in the magnitude of motion between the two component wave vibrations seem to depend, in the cases of the 1st and 2nd preliminary tremors, and the 1st and 2nd phases of the principal portion, chiefly on the predominance or comparative absence of slow movements.

* In this connection, the reader is referred to Dr. Imamura's paper: "Note on the Direction and Magnitude of the vibrations in the Different Phases of the Earthquake Motion." *The Bulletin*, Vol. I, No. 3.

Of the sections later than the 3rd phase of the principal portion, the 8th, or the commencement of the end portion seems to be due to the transverse motion. (See the *Publications*, No. 13.)

163. *Paths of Earthquake Propagation.* That the vibrations of the 3rd, and in many cases strongest, phase of the principal portion are propagated along the earth's surface seems to be evident, their transit velocity being the same as that of the ordinary macroseismic or sensible earthquake motion of near origin. It thus seems that the principal energy of the earthquake shock is propagated not through the earth's interior, the observations having shown so far no positive instance of such seismic transmission to places at a considerable distance from the origin of disturbance. In the case of the Kangra earthquake, the furthest station was Tacubaya, whose epicentral areual distance was a little more than $\frac{1}{3}$ of the whole earth's circumference; the different velocities for Tacubaya, however, not showing an evidence of the internal direct transmission. The improbability of the chord hypothesis has already been pointed out in § 118.

As regards the preliminary tremors, I have stated in the *Publications*, No. 5, a supposition that the disturbances with the transit velocity v_1 probably travels parallel to the earth's surface at some constant depth, the formation of the small vibrations in the 1st preliminary tremor being explained as follows:—A small part of the seismic energy communicated in a downward direction at the origin causes some feeble shaking to be propagated towards the earth's interior. Such a disturbance travels with a high velocity of over 10 km/sec., along a layer some depth below the surface, and would constitute a progressive source of stress and give a sort of impetus to the upper layer of the earth's

crust in a given region; the latter being consequently thrown into its own proper oscillations of periods P_1 , P_2 , etc.

The layer here considered may be supposed as marking the limit beyond which, the seismic waves are, on account of some physical properties of the underlying medium, unable to penetrate.*

Fig. 20.



- ab* . . . Earth's Surface.
- cd* . . . Path of 1st Prel. Tremor Vibrations.
- o* . . . Earth's Centre.
- s* . . . Observing Station.

One method of explaining the discrepancy between the velocities calculated by the "direct method" and the corresponding values calculated by the "difference method"

is to suppose the layer in the above hypothesis to be tolerably deep. Dr. Imamura thinks, as results of his studies in this connection, the depth of the layer in question to be several hundred kilometres.† Diagrammatically the paths of the vibrations of the 1st preliminary tremor and the 3rd phase of the principal portion would be respectively somewhat like *ocds* and *os* in Fig. 20.

164. Conclusion. There are many points to be discussed in connection with the teleseismic motion, which have not been touched upon in the foregoing pages. A comparison of the observations of the Kangra earthquake with those relating to the Assam and Bengal earthquake of 1897 and other large recent earthquakes is reserved for a future occasion. Whether the comparatively low transit velocities of the Kangra earthquake were connected with the continental origin requires further studies.

* Prof. H. Nagaoka has proposed a theory of the layer, along which the propagation velocity is maximum. See the *Publications*, No. 4.

† A. Imamura: "On the Transit velocity of the Earthquake motion originating at a near distance." The *Publications*, No. 18.

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